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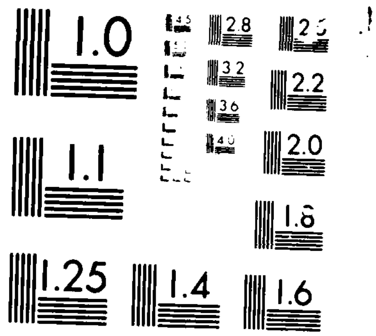
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AFWAL-TR-85-2087

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# F100 FUEL SAMPLING ANALYSIS: FOREIGN SAMPLES

L.O. Maurice

Fuels Branch
Fuels and Lubrication Division

March 1986

Final Report for Period April 1984 - April 1985



AERO PROPULSION LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
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This technical report has been reviewed and is approved for publication.

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Fuel pump cavitation problems experienced with the F100 engine used in the F-15/F-16 aircraft have led to an extensive fuel analysis program to identify fuel properties that might be contributing to fuel pump failure. This report analyzes the chemical and physical properties of 12 JP-4 and 4 JP-8 fuel samples obtained from Foreign National Air Bases. The fuels analyzed met specifications in all but a few isolated cases, and had no unusual properties. If the fuel used is causing fuel pump failure, it must be the result of a property not being measured. The fuels are as good or better than their specifications prescribed. It is concluded that the F100 fuel pump cavitation problems are most likely associated with the mechanical complexity built into the design, rather than the result of the fuel used.

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# FOREWORD

This F100 Fuel Samples Analyses program was conducted by the Fuels Branch of the Aero Propulsion Laboratory, Air Force Wright Aeronautical Laboratories, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. The work was performed under Work Unit 30480591. Ms Lourdes Q. Maurice was the Project Engineer.

This report presents physical and chemical analyses of aviation turbine fuel used in F100 engines at Foreign National Air Force Bases. Attempts are made to correlate fuel properties to fuel pump cavitation problems.

The author wishes to extend gratitude to Ms Tina Allen for her assistance in preparing portions of this report. Mr Tim Dues' valuable technical advice is also appreciated. The efforts of the Air Force Quality Control Laboratory, SA-ALC/SFTLA, in providing fuel analysis are also gratefully acknowledged.

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| AFWAL/POSF | Aero Propulsion Laboratory's Fuels Branch |
| API | American Petroleum Institute |
| ASD/YZF | Tactical Engines Program Office |
| ASTM | American Society for Testing and Materials |
| BOCLE | Ball-on-Cylinder Lubricity Evaluator |
| $^oC$ | degrees Celsius |
| cm | centimeter |
| $\Delta$ | Delta, mathematical change |
| $^oF$ | degrees Fahrenheit |
| FIA | Fluorescent Indicator Adsorption |
| FSII | Fuel System Icing Inhibitor |
| $ft^3$ | cubic feet |
| g | cubic feet |
| g | grams |
| $H_2SO_4$ | sulfuric acid |
| Hg | mercury |
| JFTOT | Jet Fuel Thermal Oxidation Tester |
| kPa | kilo pascal |
| m | minute |
| max | maximum |
| min | minimum |
| mm | millimeter |
| mm Hg | millimeter of mercury |
| NO | nitric oxide |
| P | pressure |
| P&WA | Pratt & Whitney Aircraft |
| PDC | Preheater Deposit Code |
| % | percent |
| ppm | part per million |
| psi | pounds per square inch |
| pS/M | picosiemens per meter |
| rpm | revolution per minute |
| SA-ALC/SFTLA | Quality Control Laboratory |
| sec | second |

## LIST OF ABBREVIATIONS (Concluded)

| | |
|---|---|
| $SO_2$ | sulfur dioxide |
| $SO_3$ | sulfur trioxide |
| US | United States |
| vol% | volume percent |
| WSD | wear scar diameter |
| wt% | weight percent |

# SUMMARY

Fuel pump cavitation problems experienced in the F-15/F-16 aircraft have led to the initiation of an intensive effort to analyze fuels used in these aircraft. Sixteen fuel samples were collected from Foreign National F-15/F-16 Air Force Bases to identify any fuel characteristics that could contribute to increased fuel pump cavitation.

The analyses included military specification tests, special chemical and physical characterization tests, as well as lubricity analyses.

Only a few fuels failed to meet specifications prescribed by Military Specifications MIL-T-5624L (JP-4) and MIL-T-83133A (JP-8). Fuels from Egypt (JP-8), Pakistan (JP-4), King Fahad, Saudi Arabia (JP-4), and King Aziz, Saudi Arabia (JP-4) failed the FSII specification. The fuels from Saudi Arabia and Pakistan failed the static conductivity specification. All three JP-4 fuel samples from Egypt, and the JP-4 sample from Rygge, Norway did not meet the simulated distillation specification requirements.

Static conductivity and FSII failures are not indicative of fuels likely to contribute to fuel pump failure. Rather, they are indicative of insufficient amounts of additives. The Air Bases concerned have been advised, and required additive concentrations are now being used. Simulated distillation failures (which are directly proportional to low vapor pressure) are indicative of poor fuel volatility. According to Perry's Chemical Engineers' Handbook (Reference 1), a fuel with lower volatility would be theoretically more likely to cause fuel pump cavitation at sea level conditions. However, it is likely that the failures noted were more the result of fuel handling techniques, rather than caused by poor volatility fuel. Since all samples received were handled by several parties, it is reasonable to presume that poor fuel handling techniques resulted in the loss of fuel light boiling constituents. This in turn would increase simulated distillation temperatures, as noted.

One of the most critical tests of this program was the lubricity test. Poor lubricity is often associated with fuel pump failure. Three of the fuels analyzed had suspect lubricity test results: those from King Fahad and King Aziz, and

Skrydstru, Denmark. These failures could be indicative of lack of corrosion inhibitor, and the parties involved have been advised of a potential problem. However, the failures observed were marginal, and since the Ball-on-Cylinder Lubricity Evaluator (BOCLE) used for lubricity analyses was the older, less repeatable model, the failures do not necessarily reflect a widespread problem. The remaining fuels all had acceptable lubricating qualities.

Chemical and physical characterization test results showed no indication of properties likely to cause fuel pump failure. The three Egyptian JP-4 samples and the Pakistani JP-4 sample had some properties that resembled JP-8 more than JP-4, but this should not present a problem because the F100 engine is qualified to operate on JP-8.

Overall, all of the fuels analyzed met specifications in all but a few isolated cases, and had no unusual properties. Aside from the fuels which lacked additives, the fuels are as good or better than the specification prescribes. If the fuels are causing fuel pump problems on the F100 fuel pump, then it must be the result of a fuel property not limited by the specification, such as surface tension.

It is therefore concluded that the F100 fuel pump cavitation problems are most likely associated with the mechanical complexity built into the design rather than the result of the fuel used.

# SECTION I

## INTRODUCTION

This report summarizes the analyses performed on 16 fuel samples (12 JP-4 fuels and four JP-8 fuels) from F-15 and F-16 Foreign National bases to identify any fuel characteristics that might be contributing to increased fuel pump cavitation and fuel pump failure. The data was collected between April 1984 and April 1985. This report contains the following five sections:

Section I is the introduction; Section II is discussion of the fuel pump cavitation problem and a summary of the samples involved in the analyses; Section III describes tests performed and the results; Section IV summarizes conclusions; and Section V offers recommendations.

# SECTION II

## BACKGROUND

As a result of fuel pump cavitation problems experienced in the F-15/F-16 aircraft, the Tactical Engines Program Office (ASD/YZF) and the Aero Propulsion Laboratory's Fuels Branch (AFWAL/POSF) jointly initiated a program to analyze aviation fuels used in those aircraft. The objective of the Fuel Analysis Program was to thoroughly analyze fuel samples from all F-16 and F-15 bases, as well as bases that often refuel these aircraft, in order to identify any fuel characteristics that might induce fuel pump cavitation.

The Fuel Analysis Program was divided into two phases. The results of Phase I, which analyzed samples for US Air Force Bases, have already been published (AFWAL-TR-85-2045). During Phase II, 16 samples from 9 foreign countries were submitted for analysis, and the results are the subject of this report. A list of samples is shown in Table 1.

In order to obtain reliable data from which sound conclusions could be derived, the same measures taken to ensure sample purity for the US Air Base samples were taken with the foreign national fuel samples. AFWAL/POSF provided each Air Base with special shipping containers, along with detailed sampling procedures. Each base was also asked to complete a questionnaire providing additional information regarding fuel suppliers, additives, and sampling techniques. Questionnaire response was poor, with only a few bases responding. The results of those questionnaires received are tabulated in Table 2 and were used to try to account for any unusual sample characteristics.

Each of the participating bases sent fuel samples to the F100 engine manufacturer, Pratt & Whitney Aircraft (P&WA). P&WA in turn shipped the samples to AFWAL/POSF at WPAFB. Two gallons and one pint of each fuel were requested. However, in several cases, insufficient fuel was received and complete analyses of the fuel sample could not be obtained. Samples received were distributed to several organizations for analyses. The Quality Control Laboratory, SA-ALC/SFTLA, performed a series of specification tests, Monsanto Research Company (under contract to the Fuels Branch) was responsible for several characterization tests, and AFWAL/POSF performed lubricity as well as characterization tests.

TABLE 1

FOREIGN NATIONAL BASES PARTICIPATING IN FUEL SAMPLING PROGRAM

| BASE | FUEL TYPE | SAMPLE CODE |
|---|---|---|
| INSHAS, EGYPT | JP-4 | 83-POSF-1004* |
| INSHAS, EGYPT | JP-4 | 83-POSF-1005* |
| EGYPT | JP-4 | 83-POSF-1268* |
| KING FAHAD, SAUDI ARABIA | JP-4 | 84-POSF-1952 |
| KING AZIZ, SAUDI ARABIA | JP-4 | 84-POSF-1951 |
| JAPAN | JP-4 | 83-POSF-1488 |
| PAKISTAN | JP-4 | 84-POSF-1744 |
| BEAUVECHAIN, BELGIUM | JP-4 | 84-POSF-2034 |
| KLEINE BROGEN, BELGIUM | JP-4 | 84-POSF-2036 |
| SKRYDSTRU, DENMARK | JP-4 | 84-POSF-2037 |
| BODO, NORWAY | JP-4 | 84-POSF-2113 |
| RYGGE, NORWAY | JP-4 | 84-POSF-2114 |
| EGYPT | JP-8 | 83-POSF-0758 |
| VENEZUELA | JP-8 | 84-POSF-1723* |
| LEEUWARDEN, THE NETHERLANDS | JP-8 | 83-POSF-2035 |
| VOLKEL, THE NETHERLANDS | JP-8 | 84-POSF-2038 |

*Insufficient sample provided for complete analysis.

TABLE 2

RESULTS OF QUESTIONNAIRE

| BASE | SAMPLING PROCEDURE | SUPPLIERS | ADDITIVES USED |
|---|---|---|---|
| KLEINE BROGEN | Samples drawn from a Bowser after refueling of an aircraft on the flight line. | NATO Pipeline/ 4th Belgian Pipeline | No information |
| BEAUVECHAIN | No information provided. | NATO Pipeline/ 4th Belgian Pipeline | No information |
| VOLKEL | From a refueling truck on the Air Base. | Defense Pipeline Organization | No information |
| LEEUWARDEN | Samples drawn from the top of a refueling truck. Hatch was opened and fuel was taken from the top level. | Defense Pipeline Organization | No information |

# SECTION III

# EXPERIMENTAL/DISCUSSION

## 1. SPECIFICATION TESTS

The Air Force Quality Control Laboratory (SA-ALC/SFTLA, Wright-Patterson Air Force Base, Ohio) performed a series of 19 specification tests on 12 of the 16 fuel samples. The results of these tests can be found in Appendix A.

All specification tests were performed using American Society for Testing and materials (ASTM) test methods and applicable Federal Test Methods prescribed by Military Specification MIL-T-5624L for JP-4 and MIL-T-83133A for JP-8. These test methods are documented in Reference 2.

Results of these tests were compared to the physical and chemical requirements prescribed by MIL-T-5624L (JP-4) and MIL-T-83133A (JP-8). With a few minor exceptions, all fuel samples analyzed were well within the specification limits.

The two Saudi Arabian samples, the Pakistani sample and the Egyptian JP-8 sample all failed the fuel system icing inhibitor (FSII) content test. The fuels appeared to have virtually no icing inhibitor additive, and although this is not a critical problem, potential harmful effects should not be overlooked. Icing inhibitor acts like "anti-freeze" in the fuel system and it also inhibits the growth of microorganisms that cause corrosion and plug filters. Thus, its absence could cause operational problems.

Since it was suspected that none of the additives recommended by the specifications were being added to the fuel samples, other additive detection tests (static conductivity and peroxides) were performed on the two Saudi Arabian and the Pakistani samples. Additional Egyptian JP-8 fuel was not available for testing.

Both the Saudi samples and the Pakistani sample failed the static conductivity test, denoting insufficient antistatic additive. Antistatic additive enables the fuel to dissipate static charge, therefore, its absence could also result in operational problems.

The peroxide test did not indicate a lack of antioxidant. However, the peroxide test is not a specification test. A positive result does indicate the absence of antioxidant, but a negative result does not assure its presence. Since neither FSII nor antistatic additive were being added, it was likely that antioxidant was also not being used. It was also possible that corrosion inhibitor was not being used. This problem is discussed in subsection 2 of this section.

Overall, both the Saudi Arabian samples and the Pakistani samples are good quality fuels with the exception of the lack of additives. The additive deficiency can easily be remedied by blending the "additive package" recommended by MIL-T-5624L and MIL-T-8133A to the fuel, and all three countries involved have been advised of the necessity to use additives.

Three JP-4 fuel samples from Egypt failed the 20% recovered simulated distillation test at Monsanto Research Corporation. The Egyptian samples and the Rygge, Norway sample failed the 50% recovered simulated distillation test. However, all the fuels met end point specification. Considering the distance traveled, and the amount of handling encountered by these fuels, it is reasonable to assume that the failures were caused by the loss of the fuel's low boiling components en route from the sampling point to the laboratory. The samples were shipped from the field to Pratt and Whitney and then to the Fuels Branch of the Aero Propulsion Laboratory. The Fuels Branch then provided samples to the Monsanto Research Corporation. Thus, there were several chances for the fuel's light ends to be lost.

A summary of specification test failures is found in Table 3.

Results of specification tests for the JP-4 samples were also compared to the average specification properties of JP-4 determined in 1980/81 (Reference 3). They were also compared to the average US F100 JP-4 samples (Reference 4). These comparisons are shown in Table 4.

The average aromatic content of the foreign JP-4 samples was lower than that for the average US F100 JP-4, but higher than 1980/81 average JP-4. An increased aromatic content is a negative trend because aromatics tend to increase visible smoke and contribute to shorter combustor life spans.

The average weight percent total sulfur of the JP-4 samples remained unchanged from the average 1980/81 JP-4 average sulfur, but was higher than the weight percent total sulfur of the average US F100 JP-4. This higher average sulfur was caused by the high total sulfur content of the two Saudi Arabian samples. Overall, the foreign average JP-4 had total sulfur content comparable with the US F100 average JP-4 total sulfur content. This is a favorable trend because when sulfur is combusted, $SO_2$ and $SO_3$ are formed which corrode certain fuel system components. Water vapor is also a combustion product, and it may combine with $SO_2$ and $SO_3$ to yield $H_2SO_4$ which attacks the turbine blades of an engine. In addition, sulfur can potentially contribute to thermal stability problems.

TABLE 3

SUMMARY OF SPECIFICATION TEST FAILURES

| TEST | SPEC LIMIT | SAMPLE LOCATION | VALUE OF PROPERTY |
|---|---|---|---|
| Fuel System Icing | 0.10 vol% min | King Fahad | 0.00 |
| Inhibitor | | King Aziz | 0.00 |
| (FSID 791 5327) | 0.15 vol% max | Pakistan | 0.01 |
| | | Egypt (JP-8) | 0.00 |
| Electrical conductivity | 200 pS/m min | King Fahad | 160 pS/m |
| | | King Aziz | 140 pS/m |
| | 600 pS/m max | Pakistan | 10 pS/m |
| Simulated Distillation | 130 °C maximum | Inshas #1 | 161 °C |
| ASTM D 2887 20% Recovered | | Inshas #2 | 160 °C |
| | | Egypt (JP-4) | 159 °C |
| Simulated Distillation | 185 °C maximum | Inshas #1 | 189 °C |
| ASTM D 2887 50% Recovered | | Inshas #2 | 188 °C |
| | | Egypt (JP-4) | 189 °C |
| | | Rygge, Norway (1) | 186 °C |
| | | Rygge, Norway (2) | 187 °C |

(1) Value determined by Air Force Quality Control Laboratory

(2) Value determined by Monsanto Research Corporation

TABLE 4

COMPARISON OF AVERAGE JP-4s

| Property | 1980/81 Study Average JP-4 | US F100 Average JP-4 | Foreign National Average JP-4 |
|---|---|---|---|
| Total Acid Number | 0.005 mg KOH/g | 0.005 mg KOH/g | 0.003 mg KOH/g |
| Vol % Aromatics | 12.6 | 14.0 | 13.6 |
| Vol % Olefins | 0.8 | 0.7 | 0.7 |
| Wt % Mercaptan Sulfur | 0.0004 | 0.0002 | 0.001 |
| Wt % Total Sulfur | 0.04 | 0.02 | 0.04 |
| Vapor Pressure, psi | 2.6 | 2.29 | 2.5 |
| API Gravity | 54.2 | 53.9 | 54.5 |
| Net Heat of Combustion MJ/kg | 43.5 | 43.5 | 43.6 |
| Smoke Point, mm | 27.0 | 25 | 27 |
| Wt% Hydrogen Content | 14.3 | 14.2 | 14.4 |
| Thermal Stability, PDC | < 3 | < 2 | < 1 |
| Thermal Stability, ΔP | 1 mm Hg | 2 mm Hg | 0 mm Hg |
| Existent Gum | 0.8 mg/100 ml | 0.4 mg/100 ml | 0.5 mg/100 ml |
| Vol % FSII | 0.13 | 0.13 | 0.11 |

The existent gum content of the foreign JP-4 was reduced from the 1980/81 average JP-4, but was greater than the US F100 average JP-4. Large quantities of gum in a fuel are indicative of contamination of higher molecular weight components or particulate matter. Turbine engines that use prevaporizer fuel tubes are known to be sensitive to existent gum. Thus, lower existent gum is a favorable trend.

The vol % FSII content of the foreign JP-4 was lower than both the 1980/81 and US F100 average JP-4. This problem was already discussed.

The Total Acid Number decreased over both the 1980/81 and US F100 average JP-4. This test is a measure of the level of organic acids in the fuel. These acids tend to cause corrosion problems, thus a lower total acid number is an improvement.

The olefin content decreased over the 1980/81 average olefin content and was identical to the US F100 average JP-4 olefin content. Lower olefins can reduce stability problems caused by the gum-forming tendencies of olefins.

Weight percent mercaptan sulfur content decreased overall. This is a favorable trend because some sulfur compounds, such as mercaptans, attack elastomers, and solubilize trace metals such as copper, which can cause thermal stability problems.

Vapor pressure of the foreign JP-4 was slightly lower than the 1980/81 average JP-4 vapor pressure, but was much improved from the US F100 average JP-4. Fuels with low vapor pressure do not vaporize readily, which could lead to difficult starting at low temperatures. Also, fuel vapor pressure is theoretically inversely proportional to fuel pump cavitation. Thus, lower fuel vapor pressures could tend to increase fuel pump cavitation.

API gravity was higher than both the 1980/81 JP-4 and US F100 average JP-4. A higher API gravity would indicate lower density, which would be favorable for some systems. However, a lower API gravity indicates overall a tendency towards denser fuels. This increases volumetric heat of combustion, and in turn increases volume-limited aircraft range, thus lower API gravity could also be beneficial.

Hydrogen content increased overall, and smoke point increased over the F100 and average JP-4. Smoke point and hydrogen content are closely related, and they show a favorable trend. High hydrogen content/smoke point fuels have good combustion properties, lead to longer combustor life and result in less smoke emissions.

Net Heat of Combustion was higher on a gravimetric basis as a result of the lower average density. The thermal stability remained nearly the same.

2. LUBRICITY TEST

This test evaluates the lubricity characteristics of a fuel sample. In recent years, turbine fuel specifications have become increasingly restrictive, in particular with respect to thermal stability and cleanliness. The demand for turbine fuel has also increased, and new processes have been introduced to satisfy both demand and quality. However, production of cleaner fuels has tended to remove some of the compounds that make fuel a good lubricating agent. Fuel is required by design to lubricate certain components of the fuel system, particularly fuel pumps and fuel controls. Poor lubricity can affect the life cycle of these components, and in cases of low lubricity fuel can even result in fuel pump failure.

The lubricity of the fuel samples was evaluated using the modified Furey Ball-on-Cylinder Lubricity Evaluator (BOCLE) test rig (Reference 5). The test consists of contacting a stationary, loaded test ball perpendicular to a rotating cylinder. The cylinder and ball are located in a rectangular test cell, and the cylinder is approximately one-third immersed in the test fluid. The remaining portion of the cylinder and the ball are exposed to a controlled environment which consists of air having a moisture content of less than 20 ppm. The standard operating conditions for the test are: 1000 gm applied load, 240 rpm cylinder speed, dry air environment with 0.5 L/m indirect purging, and 25°C fuel temperature. The lubricity of the fuel is evaluated by measuring the average wear scar diameter (WSD) on the ball generated by the rotating cylinder. Based on data obtained for fuel samples known to be good lubricating agents, a fuel's lubricity is considered marginally acceptable if the average diameter of the wear scar is less than 0.45 mm.

The results of lubricity tests for 13 of the 16 fuel samples analyzed are presented in Table 5 and Figure 1. A fuel lubricity problem would be one of the most likely ways in which a fuel could cause fuel pump failure, thus these data were thoroughly studied.

The wear scar diameters of the 13 samples ranged between 0.259 mm and 0.455 mm, with an average wear scar diameter of 0.38 mm. This average is the same as that for the US F100 samples. However, three of the fuel samples had suspect wear scars. The samples from the two Saudi Arabian bases and the sample from Denmark had wear scars of 0.455, 0.443, and 0.44 respectively. These are higher than normally seen

TABLE 5

LUBRICITY ANALYSES

| Fuel Sample | Average WSD (mm) |
|---|---|
| JP-4 fuels | |
| 1. Inshas, Egypt | N/A |
| 2. Inshas, Egypt | N/A |
| 3. Egypt | N/A |
| 4. King Fahad, Saudi Arabia | 0.455 |
| 5. King Aziz, Saudi Arabia | 0.443 |
| 6. Japan | 0.335 |
| 7. Pakistan | 0.383 |
| 8. Beauvechain, Belgium | 0.39 |
| 9. Kleine Brogen, Belgium | 0.35 |
| 10. Skrydstru, Denmark | 0.44 |
| 11. Bodo, Norway | 0.333 |
| 12. Rygge, Norway | 0.338 |
| JP-8 fuels | |
| 13. Egypt | 0.414 |
| 14. Venezuela | 0.259 |
| 15. Leeuwarden, The Netherlands | 0.43 |
| 16. Volkel, The Netherlands | 0.34 |

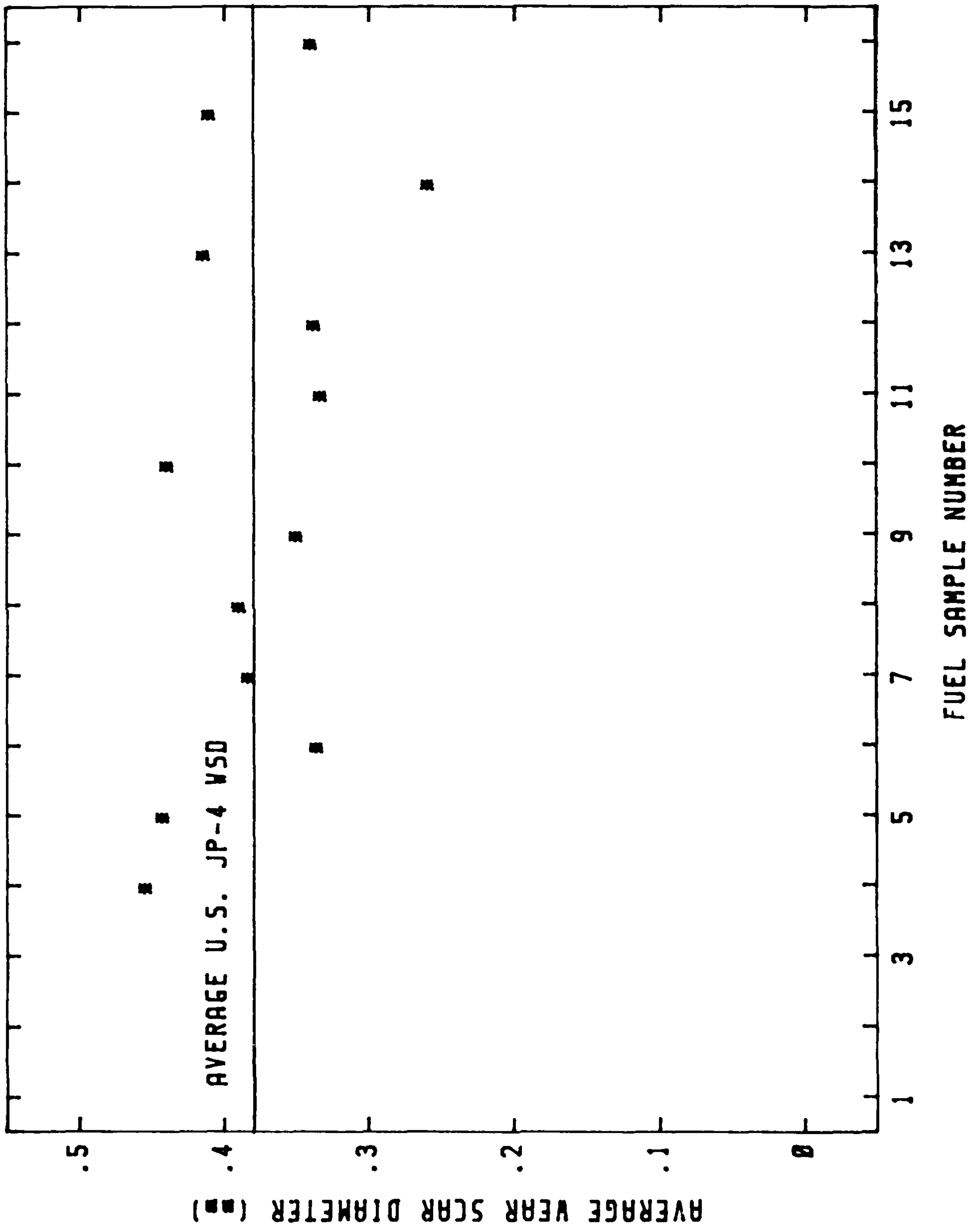


Figure 1. Lubricity Results

for JP-4 (0.35 - 0.40 mm). These high wear scar diameters suggest a possibly low corrosion inhibitor content. Corrosion inhibitor enhances the lubricating qualities of jet fuel, in addition to preventing corrosion of fuel system components. Insufficient amount of corrosion inhibitor can result in decreased life of engine components, such as the fuel pump. However, it must be kept in mind that the BOCLE test is not a specification requirement, thus its results cannot be used to rate a fuel unacceptable.

As in the previous discussion on additives, low level of corrosion inhibitor can be easily remedied by utilizing the "additive package" recommended by MIL-T-5624L.

The Pakistani sample, which had no anti-icing additive or antistatic additive had adequate lubricity. None of the other fuel samples appeared to have any adverse lubricity characteristics that might cause fuel pump problems.

3. CHARACTERIZATION TESTS

a. Description

Monsanto Research Corporation, Dayton Laboratory, performed a series of characterization tests (Reference 6). These tests were not necessarily specification tests, and were initiated to provide additional information about the fuel samples aside from specification tests. The tests performed were:

Physical properties as a function of temperature:
- True Vapor Pressure
- Kinematic Viscosity
- Density
- Surface Tension

Simulated Distillation by ASTM D 2887
Hydrocarbon Type by ASTM D 2789-71 and Monsanto 21-PO-38-36.
Gross Heat of Combustion by ASTM D 240
Thermal Conductivity
Specific Heat

(1) Physical Properties as a Function of Temperature

The physical properties specification tests performed by the Quality Control Laboratory are generally performed at one specific temperature and the

results are evaluated according to the pass/fail criteria provided by either MIL-T-5624L or MIL-T-83133A. The tests show whether fuel samples pass the specification criteria, but they do not show the behavior of the fuel over a wide temperature range. The fuels analyzed for the F100 sampling program were suspected of possibly contributing to pump failure, and thus it was desired to study the physical properties of the samples over a wide temperature range to possibly identify any fuel characteristics that might contribute to fuel pump failure.

The true vapor pressure was measured using ASTM D 2551. The method consists of introducing a fuel sample of known volume into an evacuated, temperature controlled vessel. The pressure in the chamber is read with a mercury manometer attached to the apparatus. The pressure read is the sum of the vapor pressure and the partial pressure due to any dissolved air in the sample, therefore, the vapor pressure measurement is preceded by an operation to degas the sample. This operation does not lead to any vapor losses. The vapor pressure was measured at 32, 70, 100, and 140°F and fitted to an equation of the form:

$$\log P = A - B/T$$

where:

P = vapor pressure

T = temperature

A,B = constants

The equation can then be used to determine vapor pressures at various temperatures.

The kinematic viscosity of the various samples was measured at -20, -4, 32, 100, and 140°F using ASTM D 445. This test method has been previously described in Reference 2. Viscosity was measured at the various temperatures and the results were plotted on standard ASTM viscosity temperature charts which serve to determine kinematic viscosities at other temperatures.

The density of the fuel samples was measured at -20, 32, 59, 70, 100, and 140°F using a pyrex dilatometer. The method consisted of introducing a fuel sample into a dilatometer, then bringing the sample up to the desired temperature by immersing the dilatometer in a constant temperature bath. After temperature equilibrium was established, the dilatometer scale was read with a cathemometer (Reference 6). The density was then plotted as a function of temperature.

The surface tension was measured at 32, 70, 100, and 140°F using the capillary rise method (Reference 6). The surface tension was calculated using the following expression:

$$\frac{rhdg}{2\cos\theta}$$

d = density of liquid, g/cm$^3$

h = height of column of liquid, cm

g = acceleration of gravity, cm/sec

r = radius of the capillary, cm

$\theta$ = contact angle, degrees

The data obtained were plotted to obtain a relationship between surface tension and temperature.

(2) Simulated Distillation

The boiling range distribution was determined by Monsanto Research Company using ASTM D 2887. The significance of this test has been previously discussed in this report. In addition to results for specification temperatures, Monsanto provided detailed analysis of the entire boiling range.

(3) Hydrocarbon Type Analysis

This test identifies hydrocarbon types in fuel samples. Information provided includes weight percent paraffins, cycloparaffins, dicycloparaffins, alkylbenzenes, indans and tetralins, indenes and dihydronaphthalenes, and naphthalenes. Paraffins are the most chemically inert compounds present in turbine engine fuel, thus they are more stable in storage and under thermal stresses. These compounds also have a minimum solvent and swelling effect on elastomers. Cycloparaffins are similar to straight chained paraffins, although their properties are slightly less desirable. Aromatics do have a high heating content per unit volume, but they do not burn cleanly and have a high solvent and swelling effect on elastomers. Hydrocarbon types were determined by mass spectrometry using both a modification of ASTM D 2789 (Reference 2) and Monsanto 21-PO-38-63 (Reference 6). Both of these analyses are based on summing characteristic mass spectral lines for each compound type, and constructing a matrix of n equations relating each of the n

hydrocarbon types to the summed peak values. The simultaneous equations are then solved to provide a quantitative measure of each compound type present in the fuel sample.

(4) Thermal Conductivity Analysis

Monsanto Research Corporation measured the thermal conductivity of two of the fuel samples. The thermal conductivity of a fuel is that thermal property which controls the rate at which heat can flow by conduction through the fuel. A fuel with low thermal conductivity may not be able to perform as a "heat sink" in aircraft, thus possibly causing thermal stability problems.

The thermal conductivity was determined using a transient hot wire apparatus built by Monsanto Research Corporation, St. Louis. The method consists of applying a constant heating current to a resistant wire immersed in fuel. The change in temperature of the wire is obtained from the voltage drop across the wire and known resistance-temperature characteristics (Reference 6). The remaining 14 fuel samples were not analyzed by this method because the procedure is rather lengthy and time-consuming and does not provide information that is vital to identify fuel properties that might cause fuel pump cavitation.

(5) Specific Heat

The specific heat of nine of the samples was measured with a Perkin-Elmer differential scanning calorimeter, Model DSC-1. The calorimeter is used to measure the heat flow into a sample whose temperature is linearly programmed. The specific heat is calculated by comparing the rate of heat from the sample with the rate of heat flow from a standard whose specific heat is known.

The specific heat of the fuel samples was determined by this test. The heat capacity of a fuel is directly proportional to the types of hydrocarbons that make up the fuel. The variations in specific heat between different fuels is usually in the range of +/- 7%, which could lead to a difference of 30 to 40°C in peak temperature of fuel emerging from the fuel system heat exchangers. Thus, a higher specific heat will result in improved thermal stability (Reference 7).

b. Results

Characterization test results can be found in Appendix B.

(1) Physical Properties

(a) Vapor Pressure

Monsanto evaluated the vapor pressure as a function of temperature of 14 of the 16 samples. Some difficulties were encountered when measuring the vapor pressure of the samples from Bodo and Rygge, thus no vapor pressure data are presented for these samples.

The vapor pressure of the fuel samples as a function of temperature was compared to the typical vapor pressure of JP-4 or JP-8 as a function of temperature (Reference 8).

The average foreign JP-4 samples had lower vapor pressures than the average US F100 JP-4 sample, with one exception: the foreign JP-4 had higher than typical JP-4 vapor pressure at 0°C. Samples with particularly poor vapor pressure included the two JP-4 fuels from Inshas, the Egyptian JP-4, and Pakistani fuels. Theoretically, the lower than average vapor pressure could lead to increased fuel pump cavitation. However, this correlation is generally valid at sea level condition, and may not be applicable to the aircraft's entire range.

The JP-8 samples had very low vapor pressure, as expected. Since, as stated previously, lower vapor pressure fuels may lead to increased pump cavitation, the use of JP-8 in the F100 engine could lead to increased pump cavitation. However, it must be stressed again that this correlation may not apply throughout the aircraft's entire operating range.

(b) Kinematic Viscosity

Monsanto also measured the kinematic viscosity as a function of temperature of the 16 samples. There are no specifications against which to judge the viscosity of JP-4, but the data obtained was compared to typical JP-4 kinematic viscosity measurements (Reference 8). All the JP-8 samples met the viscosity specifications (8 cS maximum at -20°C). The kinematic viscosity as a function of temperature of the F100 JP-8 samples was also compared to typical JP-8 viscosity measurements (Reference 8).

The average foreign F100 sample has higher kinematic viscosity than the average JP-4 US F100 sample and typical JP-4. However, this high average was mainly caused by a few samples; most of the fuels had typical kinematic viscosity. All the Egyptian JP-4 samples and the Pakistani sample had exceptionally high kinematic viscosity. The Pakistani sample had a kinematic viscosity profile which more closely resembled JP-8 than JP-4. The higher than typical viscosity, especially at low temperatures, is likely to decrease fuel pumpability, and thus could lead to increased pump failures. However, since the F100 fuel pump is designed to operate on JP-8, these fuels should not result in unusual operational problems.

All F100 JP-8 fuel samples had lower average viscosity at low temperatures than typical JP-8 fuel. On the other hand, the samples had higher average viscosity at high temperatures. High kinematic viscosity affects fuel pumpability more at the lower temperatures than at the higher temperatures. Thus, since the F100 JP-8 samples have better than typical pumpability at low temperatures, they are less likely to cause fuel pump failures.

(c) Density

The average density of the foreign JP-4 F100 samples is slightly higher than the average density of typical JP-4 and US F100 JP-4. Again, the Egyptian and Pakistani samples were the cause of the high average. However, the density of all the samples is below typical JP-8 density. Since the F100 pump is designed to operate on JP-8, none of the JP-4 fuel samples should lead to unusual operational problems.

The density of the JP-8 samples was lower than that of typical JP-8 fuel. No unusual problems were noted.

(d) Surface Tension

Low surface tension favors the atomization and ignition of fuel droplets (Reference 7). Monsanto measured the surface tension of the 16 foreign F100 samples versus temperature, and results were compared with typical JP-4 and JP-8 surface tensions at varying temperatures.

The average surface tension of the JP-4 samples is higher than the typical surface tension of JP-4 and the average US F100 JP-4 sample. Again, the Egyptian samples and the Pakistani sample are responsible for the high

average. The high surface tension would tend to negatively impact ignition characteristics as compared to typical JP-4. However, the differences are of such low magnitude that no noticeable loss of performance is likely to occur.

(2) Thermal Properties

(a) Thermal Conductivity Analyses

Thermal conductivity analyses were only performed on two JP-4 fuel samples. The results were compared to the typical thermal conductivity values of JP-4 and the average US F100 JP-4. No unusual characteristics were noted.

(b) Specific Heat

The specific heat as a function of temperature of seven of the foreign JP-4 and two of the foreign JP-8 F100 samples was calculated and compared to typical JP-4 and average US F100 JP-4 specific heat and typical JP-8 specific heat at various temperatures. All foreign F100 samples had lower than typical specific heat. The lower specific heat would indicate a tendency towards poorer thermal stability, but not towards increased fuel pump cavitation problems.

(3) Chemical Composition

(a) Boiling Point Distribution

The simulated distillation data was obtained by Monsanto for 15 of the 16 foreign F100 samples. No simulated distillation data are reported for the Bodo sample, since some difficulty was encountered during this test.

No abnormalities are noted in the distillation curves, with the exception of the curves for the two Inshas samples, the Egyptian JP-4, and the Rygge samples. These four samples failed the boiling point distribution specifications, and their distillation curves have higher slopes than normal JP-4 distillation curves.

(b) Hydrocarbon Type Analyses

Hydrocarbon type analyses were performed by both modified ASTM D 2789-71 and Monsanto methods. To determine which test method was more applicable to the F100 samples, the average carbon number of the samples was measured by mass spectrometry. The average carbon numbers were in the 7 to 9 range which indicates that the samples are more compatible with the modified ASTM test method.

Hydrocarbon types measured included paraffins, cycloparaffins, dicycloparaffins, alkylbenzenes, indans and tetralins, and indenes and dihydronaphthalenes.

The average paraffin content for the JP-4 samples was 56.1 wt%, with values ranging from 64.8 wt% for the King Aziz sample to 49.2 wt% for the Inshas #1 sample. The average cycloparaffin content was 27.4 wt%, with values ranging from 34.7 wt% for the Egyptian JP-4 sample to 16.9 wt% for the king Aziz sample. The dicycloparaffin content was low, ranging from 0 wt% for several samples (all the Egyptian and the Rygge samples) to 5.3 wt% for the Skrydstru sample. As compared to the average US F100 JP-4, the foreign samples generally have higher normal paraffins and lower cycloparaffins. However, total paraffin content is nearly identical.

The JP-8 samples' average paraffin content was 44.5 wt%, with the Venezuelan sample having a rather low paraffin content of 38.3 wt%. The average cycloparaffin content was 36.3 wt% and the average dicycloparaffin content was 0.2 wt%. Total average paraffins was 81.0 wt%. The higher than JP-4 cycloparaffin content accounts for some of the higher density of JP-8.

The average alkylbenzene content for the JP-4 samples was 12.6 wt%. Values range from 16.0 wt% for the Bodo sample to 9.5 wt% for the Skrydstru sample. The indans and tetralins content was low, averaging 1.7 wt%. Values ranged from 3.0 wt% for the Rygge sample to 0.4 wt% for the Bodo sample. The naphthalene content was also low. The average naphthalene content was 1.0 wt%, with values ranging 2.2 wt% for the Inshas #1 sample to 0.1 wt% for the Skrydstru sample. The total aromatic content of the foreign F100 JP-4 samples is nearly identical to that of the average US F100 JP-4 sample. The European samples normally had lower total aromatic content.

The JP-8 samples' average alkylbenzene content was 12.6 wt%. The average indans and tetralins content was 4.0 wt% and the average naphthalene content was 2.8 wt%. The average total aromatic content was 19.4 wt%. The higher than average JP-4 aromatic content would again account for the higher density of JP-8.

No unusual trends were noted in the hydrocarbon type analyses. However, the three Egyptian JP-4 samples were not "typical". They had lower than typical normal-paraffin content, and higher than typical aromatic content. In fact, these samples resembled JP-8 in several other ways (viscosity, density, surface

tension). However, in all cases, properties fell between those typical of JP-4 and those typical of JP-8. Therefore, it is impossible to accurately state that the Egyptian samples were JP-8, rather than JP-4. In the case of the Pakistani sample, physical properties resembled JP-8, but hydrocarbon types resembled JP-4. In any case, even though the Egyptian and Pakistani samples are unusual, their properties should not be contributing to increased pump failure, as the F100 engine is qualified to operate on JP-8.

# SECTION IV

# CONCLUSIONS

Due to fuel pump cavitation problems experienced in the F-15/F-16 aircraft, 16 fuel samples from 9 F-15 and F-16 Foreign National Air Bases were thoroughly analyzed to possibly identify fuel properties that might contribute to increased fuel pump cavitation and/or fuel pump failure. The analyses performed did not yield any conclusive results that would indicate that the fuels being presently used at Foreign National Air Bases have any inherent characteristics that contribute to fuel pump cavitation or failure.

Only three areas resulted in fuels not meeting specification requirements: Boiling Point Distribution (four failures), Electrical Conductivity (three failures), and FSII (four failures).

FSII and Electrical Conductivity failures are not indicative of characteristics likely to cause fuel pump failure. These failures are indicative of lack of additives, a problem which is easily remedied by blending the "additive package" recommended by MIL-T-5624L and MIL-T-83133A into the fuel. The fuels that failed Boiling Range distribution specifications could theoretically have a tendency to increase fuel pump cavitation. However, the inversely proportional relationship between pump cavitation and vapor pressure (which is closely related to Boiling Range distribution) is generally valid at sea level conditions. At other operating altitudes, this relation may not be valid, thus the Boiling Range distribution failures may not cause a pump cavitation problem.

The characterization tests showed no unusual fuel properties that might lead to fuel pump failures. Most of the JP-4 samples had vapor pressure, kinematic viscosity, surface tension, and density as a function of temperature comparable to typical JP-4. A few samples had lower than typical vapor pressure, and higher than typical kinematic viscosity, surface tension and density. However, all the properties were similar to those of JP-8, and since the F100 engine is qualified to operate on JP-8, the unusual fuels should cause no operational problems. All the JP-8 samples had properties similar to typical JP-8, thus should cause no operational problems. Hydrocarbon type analyses also revealed no exceptional trends for any of the samples, with the exception that some of the JP-4 samples resembled JP-8.

Lubricity tests indicated that most of the samples had adequate lubricating qualities. However, three samples had results which indicated a possible lack of sufficient corrosion inhibitor additive, thus low lubricity. Since poor lubricity fuel is often blamed for fuel pump failures, these samples may present a problem. However, the lubricity test results were "borderline" and it is possible that the fuels did have corrosion inhibitor. In any case, lack of corrosion inhibitor is easily remedied by blending the previously mentioned additive package into the fuel.

Overall, most of the foreign JP-4 and JP-8 samples analyzed for the F100 fuel sampling program were well within specifications. The fuels were generally better than "typical" JP-4 and comparable to US operational JP-4. The JP-8 samples were also comparable to typical JP-8. With the exception of the fuels that lacked additives, none of the fuels used at the Foreign National Air Bases surveyed should be contributing to operational problems in the F100 fuel pump.

From this analyses program, it can be concluded that it is unlikely that extensive analyses of fuel samples not directly involved in isolated aircraft fuel pump failures will provide explanations for such incidents. In general, fuel used in the field is of very high quality, and such analyses as the F100 sampling program attest to assurances that specifications used by the US Air Force (which are also generally followed by foreign countries using US aircraft) are as viable as they were when the chemical and physical properties of JP-4 for 1980-1981 were published (Reference 3).

# SECTION V

# RECOMMENDATIONS

The recommendations derived from this report are identical to those derived from the first F100 analyses report.

Since analyzing fuel samples has not offered any clues to the fuel pump cavitation problem, it is recommended that the cavitation problem be studied at a more fundamental level. Fuel pump tests should be conducted to determine if any fuel characteristics not limited by the specification can be causing fuel pump failure.

This analysis is an excellent survey of operational fuels. It does serve to identify problems such as lack of additives. However, if the fuel is causing a fuel pump problem on the F100 fuel pump, it must be the result of a fuel property not being measured, or one that has never been related to pump failure before. It is more likely that the F100 fuel pump cavitation problems are associated with the mechanical complexity built into the design of the pump, rather than the result of the fuel used. A different approach must be taken to resolve the F100 fuel pump failure problem.

Since a lack of additives problem was identified in several fuels, it was recommended that the additive package be added to these fuels. Once the additive problem was identified, the proper authorities were immediately advised of the problem. It is the Fuel's Branch understanding that additives are now being used at all the problem Air Bases. It is again stressed that the recommended additives should continue to be used to prevent future potential operational problems.

# APPENDIX A

# SPECIFICATION ANALYSES

TABLE A-1

SAYBOLT COLOR

Spec: No Limit

| FUEL (JP-4) | SAYBOLT COLOR |
|---|---|
| 1. Inshas, Egypt | N/A |
| 2. Inshas, Egypt | N/A |
| 3. Egypt | N/A |
| 4. King Fahad, Saudi Arabia | 30 |
| 5. King Aziz, Saudi Arabia | 30 |
| 6. Japan | 30 |
| 7. Pakistan | 30 |
| 8. Beauvechain, Belgium | 21 |
| 9. Kleine Brogen, Belgium | 27 |
| 10. Skrydstru, Denmark | 30 |
| 11. Bodo, Norway | 30 |
| 12. Rygge, Norway | 27 |
| Mean: | 28 +/- 3 |

Spec: No Limit

| FUEL (JP-8) | SAYBOLT COLOR |
|---|---|
| 1. Egypt | 26 |
| 2. Venezuela | N/A |

## TABLE A-2

## TOTAL ACID NUMBER ANALYSES

| FUEL (JP-4) | TOTAL ACID (mg KOH/gm) |
|---|---|
| Spec: 0.015 mg KOH/g maximum | |
| 1. Inshas, Egypt | N/A |
| 2. Inshas, Egypt | N/A |
| 3. Egypt | N/A |
| 4. King Fahad, Saudi Arabia | 0.002 |
| 5. King Aziz, Saudi Arabia | 0.001 |
| 6. Japan | 0.006 |
| 7. Pakistan | 0.003 |
| 8. Beauvechain, Belgium | 0.003 |
| 9. Kleine Brogen, Belgium | 0.005 |
| 10. Skrydstru, Denmark | 0.002 |
| 11. Bodo, Norway | 0.002 |
| 12. Rygge, Norway | 0.004 |
| Mean: | 0.003 +/- 0.002 |

| FUEL (JP-8) | TOTAL ACID (mg KOH/gm) |
|---|---|
| Spec: 0.015 mg KOH/gm maximum | |
| 1. Egypt | 0.005 |
| 2. Venezuela | N/A |
| 3. Leeuwarden, Netherlands | 0.004 |
| 4. Volkel, Netherlands | 0.003 |

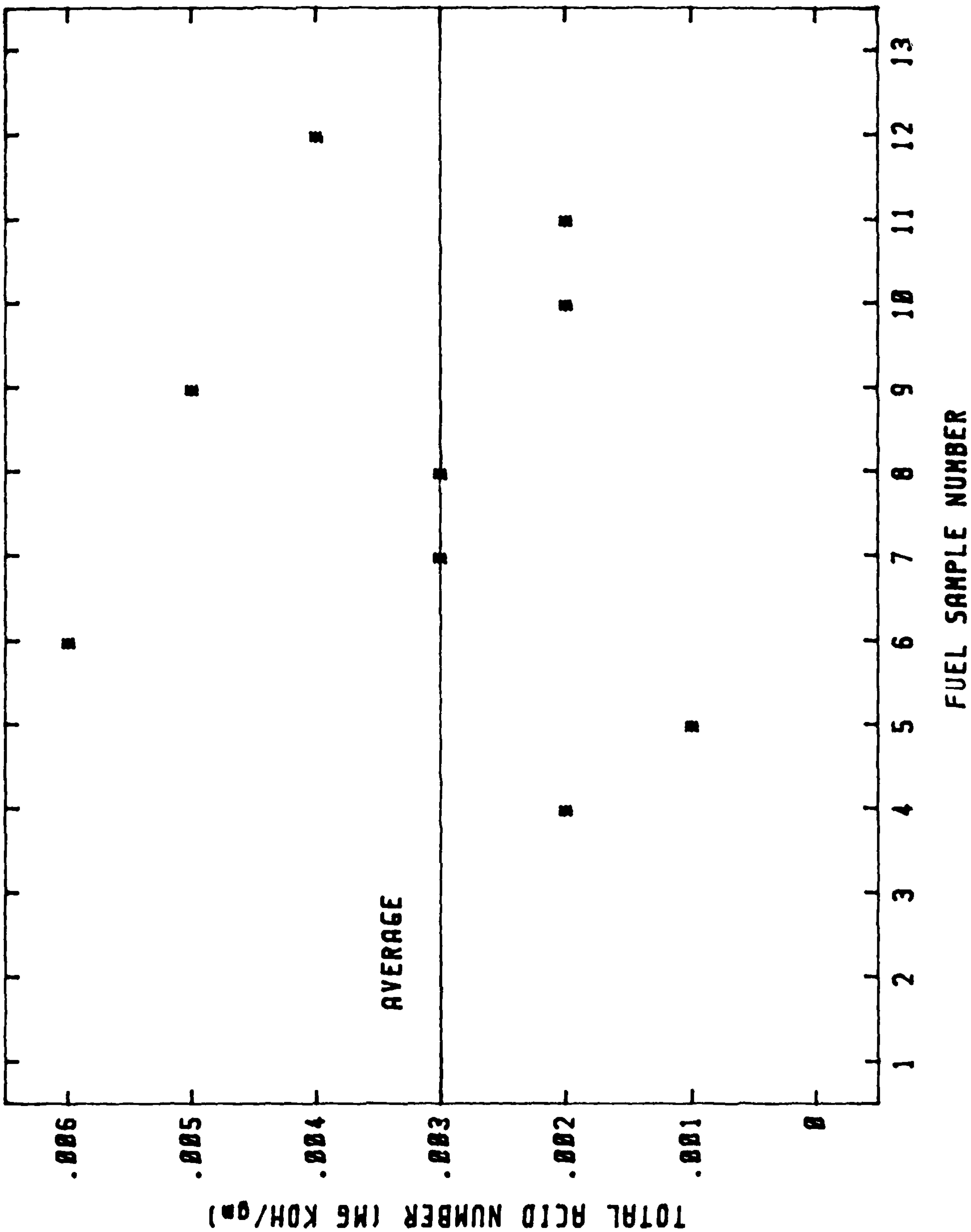


Figure A-1. Total Acid Number

## TABLE A-3

## VOLUME PERCENT AROMATICS ANALYSES

| FUEL (JP-4) | VOL % AROMATICS |
|---|---|
| Spec: 25 vol % maximum | |
| 1. Inshas, Egypt | N/A |
| 2. Inshas, Egypt | N/A |
| 3. Egypt | N/A |
| 4. King Fahad, Saudi Arabia | 13.5 |
| 5. King Aziz, Saudi Arabia | 14.5 |
| 6. Japan | 13.4 |
| 7. Pakistan | 14.3 |
| 8. Beauvechain, Belgium | 13.3 |
| 9. Kleine Brogen, Belgium | 12.2 |
| 10. Skrydstru, Denmark | 11.7 |
| 11. Bodo, Norway | 14.4 |
| 12. Rygge, Norway | 14.8 |
| Mean: | 13.6 +/- 1.0 |

| FUEL (JP-8) | VOL % AROMATICS |
|---|---|
| Spec: 25.0 vol % maximum | |
| 1. Egypt | 16.3 |
| 2. Venezuela | N/A |
| 3. Leeuwarden, Netherlands | 15.6 |
| 4. Volkel, Netherlands | 20.8 |

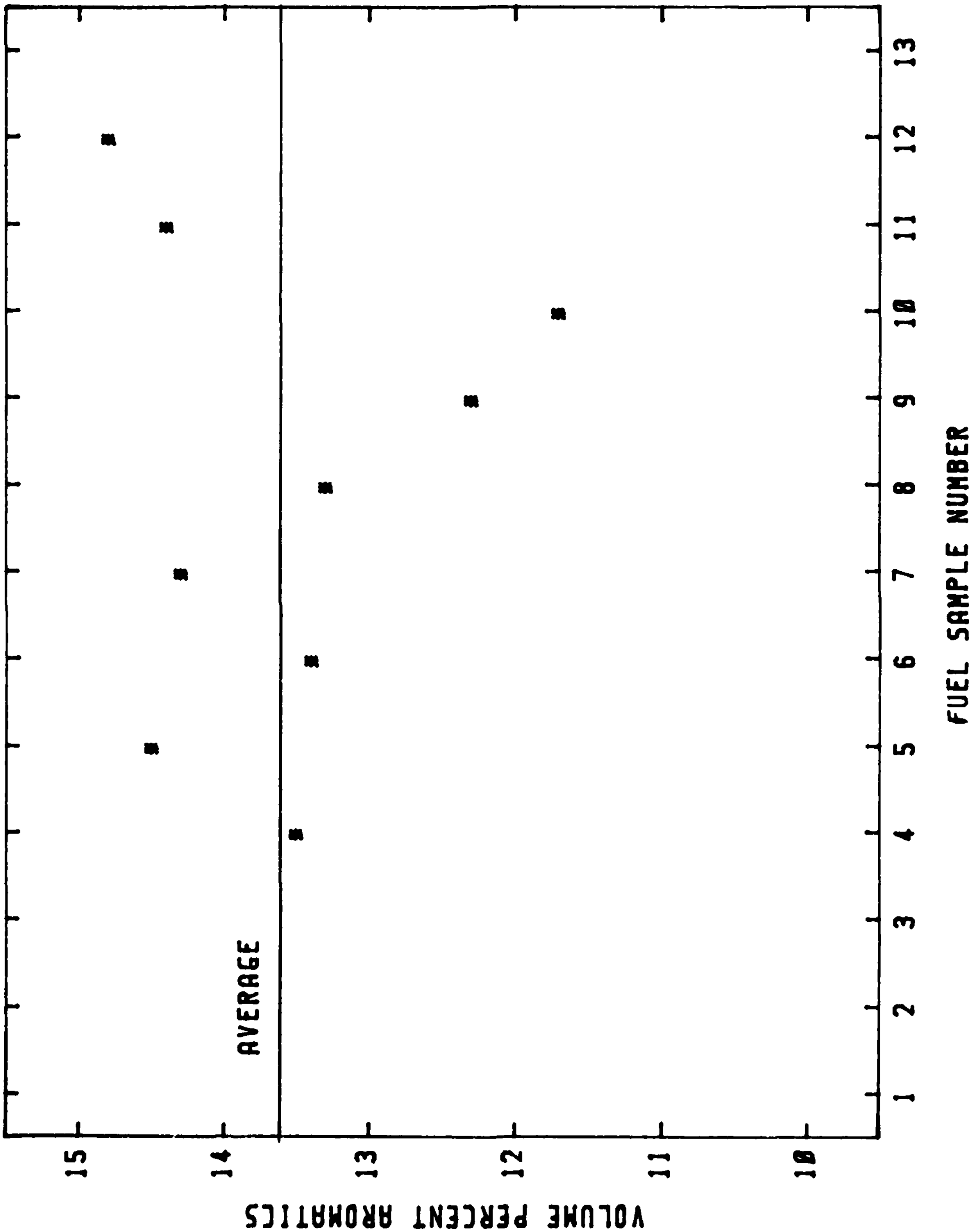


Figure A-2. Volume Percent Aromatics

TABLE A-4

VOLUME PERCENT OLEFINS ANALYSES

| FUEL (JP-4) | VOL% OLEFINS |
|---|---|
| Spec: 5 vol % maximum | |
| 1. Inshas, Egypt | N/A |
| 2. Inshas, Egypt | N/A |
| 3. Egypt | N/A |
| 4. King Fahad, Saudi Arabia | 0.5 |
| 5. King Aziz, Saudi Arabia | 0.5 |
| 6. Japan | 0.8 |
| 7. Pakistan | 0.7 |
| 8. Beauvechain, Belgium | 0.7 |
| 9. Kleine Brogen, Belgium | 0.7 |
| 10. Skrydstru, Denmark | 0.7 |
| 11. Bodo, Norway | 0.7 |
| 12. Rygge, Norway | 0.9 |
| Mean: | 0.7 +/- 0.1 |

| FUEL (JP-8) | VOL% OLEFINS |
|---|---|
| Spec: 5 vol % maximum | |
| 1. Egypt | 0.8 |
| 2. Venezuela | N/A |
| 3. Leeuwarden, Netherlands | 0.7 |
| 4. Volkel, Netherlands | 0.9 |

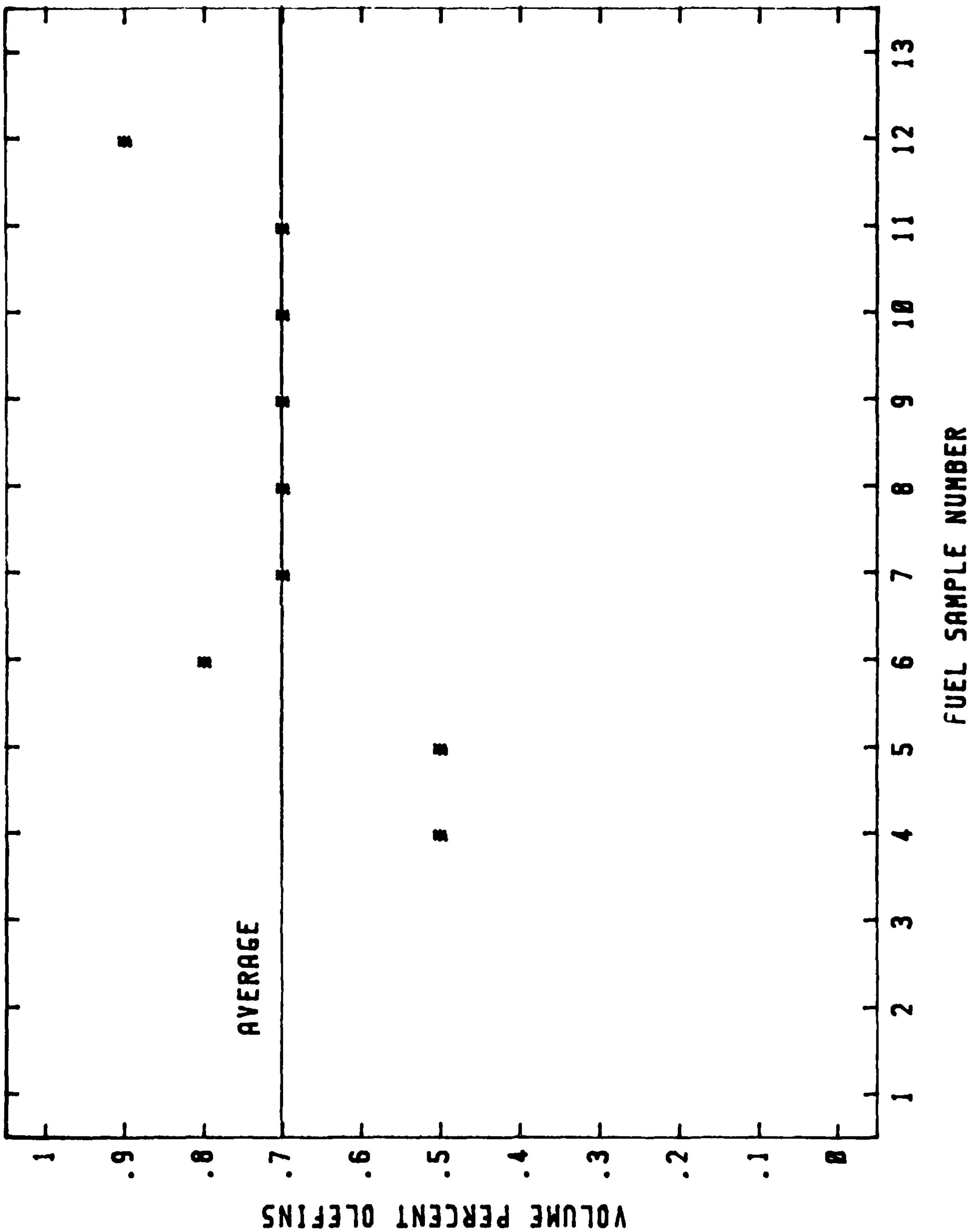


Figure A-3. Volume Percent Olefins

TABLE A-5

MERCAPTAN SULFUR ANALYSES

| FUEL (JP-4) | MERCAPTAN SULFUR wt % |
|---|---|
| Spec: 0.001 wt % maximum | |
| 1. Inshas, Egypt | N/A |
| 2. Inshas, Egypt | N/A |
| 3. Egypt | N/A |
| 4. King Fahad, Saudi Arabia | 0.0003 |
| 5. King Aziz, Saudi Arabia | 0.0004 |
| 6. Japan | 0.0000 |
| 7. Pakistan | 0.0001 |
| 8. Beauvechain, Belgium | 0.0002 |
| 9. Kleine Brogen, Belgium | 0.0001 |
| 10. Skrydstru, Denmark | 0.0000 |
| 11. Bodo, Norway | 0.0001 |
| 12. Rygge, Norway | 0.0000 |
| Mean: | 0.0001 +/- 0.0001 |

| FUEL (JP-8) | MERCAPTAN SULFUR wt % |
|---|---|
| Spec: 0.001 wt % maximum | |
| 1. Egypt | 0.0000 |
| 2. Venezuela | N/A |
| 3. Leeuwarden, Netherlands | 0.0001 |
| 4. Volkel, Netherlands | 0.0002 |

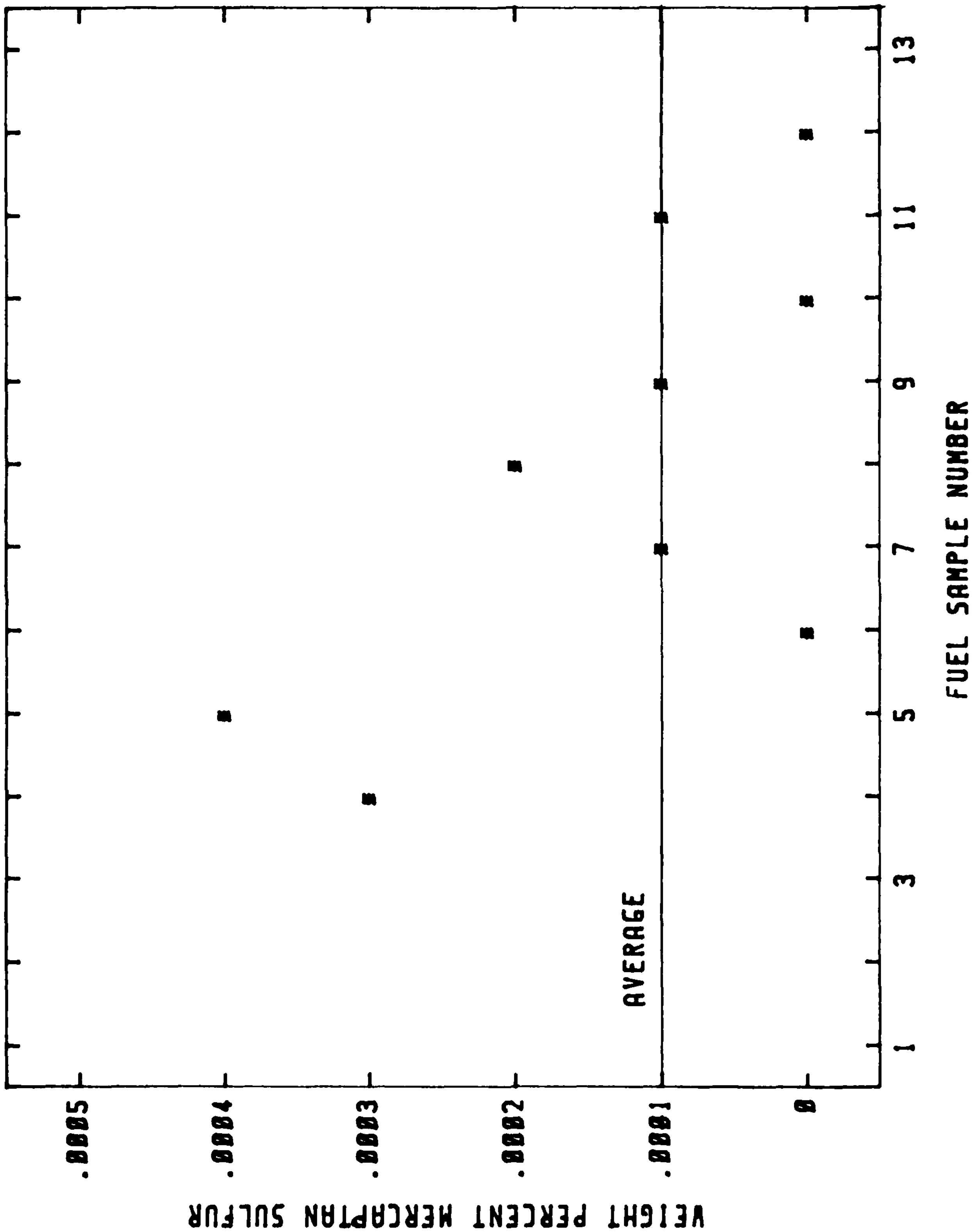


Figure A-4. Mercaptan Sulfur

TABLE A-6

TOTAL WEIGHT PERCENT SULFUR ANALYSES

| FUEL (JP-4) | WT % SULFUR |
|---|---|
| Spec: 0.40 wt % maximum | |
| 1. Inshas, Egypt | N/A |
| 2. Inshas, Egypt | N/A |
| 3. Egypt | N/A |
| 4. King Fahad, Saudi Arabia | 0.09 |
| 5. King Aziz, Saudi Arabia | 0.13 |
| 6. Japan | 0.02 |
| 7. Pakistan | 0.05 |
| 8. Beauvechain, Belgium | 0.03 |
| 9. Kleine Brogen, Belgium | 0.03 |
| 10. Skrydstru, Denmark | 0.01 |
| 11. Bodo, Norway | 0.00 |
| 12. Rygge, Norway | 0.00 |
| Mean: | 0.04 +/- 0.04 |

| FUEL (JP-8) | WT % SULFUR |
|---|---|
| Spec: 0.3 wt % maximum | |
| 1. Egypt | 0.02 |
| 2. Venezuela | N/A |
| 3. Leeuwarden, Netherlands | 0.00 |
| 4. Volkel, Netherlands | 0.00 |

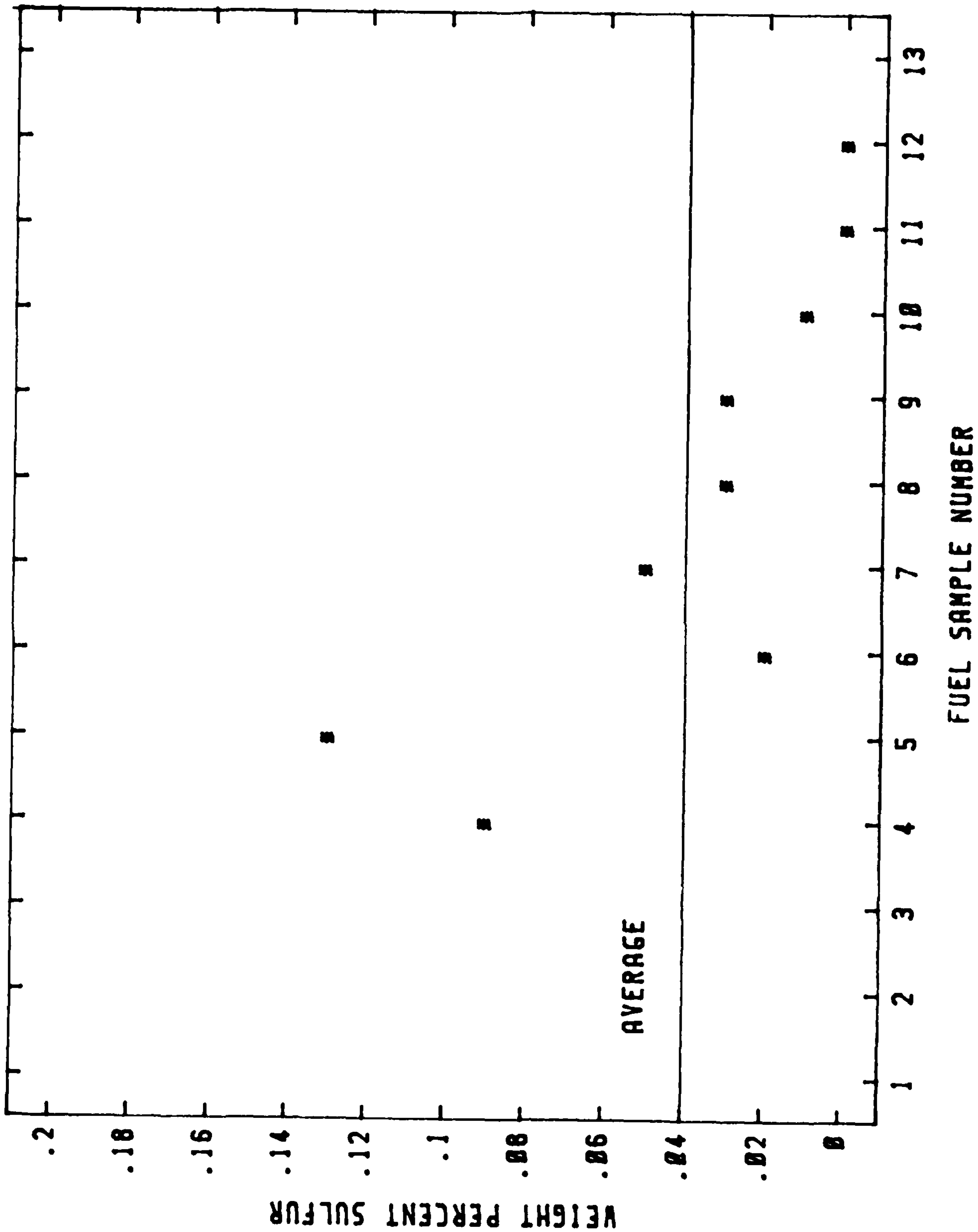


Figure A-5. Total Sulfur

TABLE A-7

BOILING RANGE DISTRIBUTION SPECIFICATIONS

ASTM D 2887 (JP-4)

| | | |
|---|---|---|
| SPECS: | 20% recovered | - 130 $^{\circ}$C maximum |
| | 50% recovered | - 185 $^{\circ}$C maximum |
| | 90% recovered | - 250 $^{\circ}$C maximum |
| | FBP | - 320 $^{\circ}$C maximum |

ASTM D 2887 (JP-8)

| | | |
|---|---|---|
| SPECS: | 10% recovered | - 186$^{\circ}$C maximum |
| | 20% recovered | - to be reported |
| | 50% recovered | - to be reported |
| | 90% recovered | - to be reported |
| | FBP | - 330$^{\circ}$C maximum |

TABLE A-8

SIMULATED DISTILLATION ANALYSES

| FUEL (JP-4) | IBP°C SFTLA | IBP°C MONSANTO | 10%°C SFTLA | 10%°C MONSANTO | 20%°C SFTLA | 20%°C MONSANTO |
|---|---|---|---|---|---|---|
| 1. Inshas, Egypt | N/A | 98 | N/A | 149 | N/A | 161 |
| 2. Inshas, Egypt | N/A | 98 | N/A | 149 | N/A | 160 |
| 3. Egypt | N/A | 98 | N/A | 146 | N/A | 159 |
| 4. King Fahad, Saudi Arabia | 24 | 31 | 68 | 70 | 98 | 100 |
| 5. King Aziz, Saudi Arabia | 24 | 27 | 68 | 65 | 98 | 95 |
| 6. Japan | 54 | 27 | 91 | 72 | 109 | 99 |
| 7. Pakistan | 24 | 28 | 82 | 74 | 106 | 102 |
| 8. Beavechain, Belgium | 24 | 29 | 73 | 57 | 99 | 14 |
| 9. Kleine Brogen, Belgium | 26 | 29 | 70 | 66 | 92 | 91 |
| 10. Skrydstru, Denmark | -5 | 14 | 92 | 91 | 112 | 112 |
| 11. Bodo, Norway | -7 | N/A | 82 | N/A | 97 | N/A |
| 12. Rggye, Norway | 24 | 37 | 82 | 87 | 116 | 119 |
| | | | | Mean: | 130 | |

| FUEL (JP-8) | IBP°C SFTLA | IBP°C MONSANTO | 10%°C SFTLA | 10%°C MONSANTO | 20%°C SFTLA | 20%°C MONSANTO |
|---|---|---|---|---|---|---|
| 1. Egypt | 99 | 98 | 144 | 150 | 160 | 164 |
| 2. Venezuela | N/A | 130 | N/A | 164 | N/A | 175 |
| 3. Leeuwarden, Netherlands | 116 | 118 | 163 | 162 | 175 | 175 |
| 4. Volkel, Netherlands | 93 | 92 | 150 | 149 | 169 | 166 |

TABLE A-8 (Concluded)

| | FUEL (JP-4) | 50% °C SFTLA | 50% °C MONSANTO | 90% °C SFTLA | 90% °C MONSANTO | FBP °C SFTLA | FBP °C MONSANTO |
|---|---|---|---|---|---|---|---|
| 1. | Inshas, Egypt | N/A | 189 | N/A | 235 | N/A | 264 |
| 2. | Inshas, Egypt | N/A | 189 | N/A | 235 | N/A | 268 |
| 3. | Egypt | N/A | 189 | N/A | 243 | N/A | 345 |
| 4. | King Fahad, Saudi Arabia | 173 | 177 | 231 | 236 | 279 | 275 |
| 5. | King Aziz, Saudi Arabia | 174 | 171 | 232 | 231 | 279 | 284 |
| 6. | Japan | 163 | 157 | 232 | 230 | 273 | 275 |
| 7. | Pakistan | 149 | 150 | 227 | 230 | 265 | 278 |
| 8. | Beavechain, Belgium | 159 | 157 | 236 | 233 | 267 | 263 |
| 9. | Kleine Brogen, Belgium | 163 | 158 | 233 | 231 | 270 | 271 |
| 10. | Skrydstru, Denmark | 164 | 162 | 234 | 232 | 283 | 268 |
| 11. | Bodo, Norway | 127 | N/A | 186 | N/A | 251 | N/A |
| 12. | Rggye, Norway | 186 | 187 | 226 | 225 | 286 | 264 |
| | Mean: | 162 | | 226 | | 273 | |

| | FUEL (JP-8) | 50% °C SFTLA | 50% °C MONSANTO | 90% °C SFTLA | 90% °C MONSANTO | FBP °C SFTLA | FBP °C MONSANTO |
|---|---|---|---|---|---|---|---|
| 1. | Egypt | 193 | 196 | 240 | 239 | 270 | 279 |
| 2. | Venezuela | N/A | 207 | N/A | 263 | N/A | 310 |
| 3. | Leeuwarden, Netherlands | 205 | 204 | 248 | 251 | 293 | 298 |
| 4. | Volkel, Netherlands | 196 | 194 | 244 | 241 | 284 | 272 |

TABLE A-9

VAPOR PRESSURE ANALYSES

| FUEL (JP-4) | VAPOR PRESSURE (psi) SFTLA |
|---|---|
| Spec: 2 psi minimum; 3 psi maximum | |
| 1. Inshas, Egypt | N/A |
| 2. Inshas, Egypt | N/A |
| 3. Egypt | N/A |
| 4. King Fahad, Saudi Arabia | 2.7 |
| 5. King Aziz, Saudi Arabia | 2.6 |
| 6. Japan | 2.5 |
| 7. Pakistan | 2.6 |
| 8. Beauvechain, Belgium | 2.7 |
| 9. Kleine Brogen, Belgium | 2.6 |
| 10. Skrydstru, Denmark | 2.5 |
| 11. Bodo, Norway | 2.5 |
| 12. Rygge, Norway | 2.2 |
| Mean: | 2.5 +/- 0.15 |

| FUEL (JP-8) | VAPOR PRESSURE (psi) MONSANTO |
|---|---|
| Spec: Not Applicable | |
| 1. Egypt | .35 |
| 2. Venezuela | .48 |
| 3. Leeuwarden, Netherlands | .42 |
| 4. Volkel, Netherlands | .82 |

## TABLE A-10

## API GRAVITY ANALYSES

| FUEL (JP-4) | API GRAVITY |
|---|---|
| Spec Limits: 45.0 and 57.0 | |
| 1. Inshas, Egypt | N/A |
| 2. Inshas, Egypt | N/A |
| 3. Egypt | N/A |
| 4. King Fahad, Saudi Arabia | 55.3 |
| 5. King Aziz, Saudi Arabia | 55.4 |
| 6. Japan | 55.6 |
| 7. Pakistan | 55.8 |
| 8. Beauvechain, Belgium | 53.4 |
| 9. Kleine Brogen, Belgium | 54.6 |
| 10. Skrydstru, Denmark | 52.9 |
| 11. Bodo, Norway | 55.6 |
| 12. Rygge, Norway | 51.5 |
| Mean: | 54.5 +/- 1.5 |

| FUEL (JP-8) | API GRAVITY |
|---|---|
| Spec: 37.0 and 51.0 | |
| 1. Egypt | 47.0 |
| 2. Venezuela | N/A |
| 3. Leeuwarden, Netherlands | 45.6 |
| 4. Volkel, Netherlands | 45.0 |

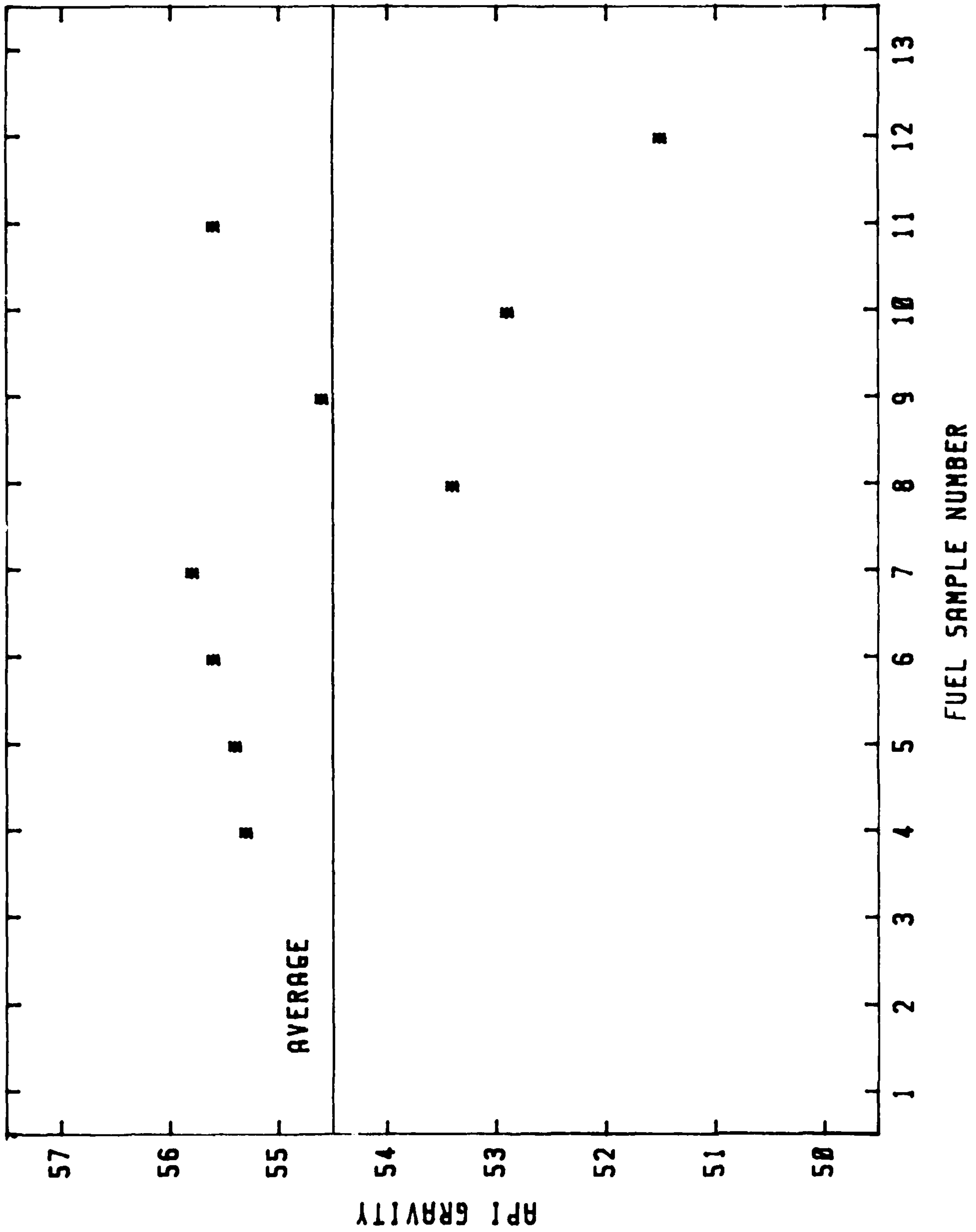


Figure A-6. API Gravity

TABLE A-11

FREEZING POINT ANALYSES

| FUEL (JP-4) Spec: $-58^{o}C$ maximum | FREEZING POINT ($^{o}C$) |
|---|---|
| 1. Inshas, Egypt | N/A |
| 2. Inshas, Egypt | N/A |
| 3. Egypt | N/A |
| 4. King Fahad, Saudi Arabia | -60 |
| 5. King Aziz, Saudi Arabia | -60 |
| 6. Japan | -63 |
| 7. Pakistan | -62 |
| 8. Beauvechain, Belgium | -65 |
| 9. Kleine Brogen, Belgium | -62 |
| 10. Skrydstru, Denmark | -60 |
| 11. Bodo, Norway | -73 |
| 12. Rygge, Norway | -63 |
| Mean: | -63 +/- 4 |

| FUEL (JP-8) Spec: $-50^{o}C$ maximum | FREEZING POINT ($^{o}C$) |
|---|---|
| 1. Egypt | -53 |
| 2. Venezuela | N/A |
| 3. Leeuwarden, Netherlands | -56 |
| 4. Volkel, Netherlands | -67 |

TABLE A-12

VISCOSITY ANALYSES

| FUEL (JP-4) | VISCOSITY SFTLA | (Cs @ -20°C) MONSANTO |
|---|---|---|
| Spec: No limit | | |
| 1. Inshas, Egypt | N/A | 3.18 |
| 2. Inshas, Egypt | N/A | 3.12 |
| 3. Egypt | N/A | 1.73 |
| 4. King Fahad, Saudi Arabia | 2.09 | 1.85 |
| 5. King Aziz, Saudi Arabia | 1.95 | 1.81 |
| 6. Japan | 1.80 | 1.70 |
| 7. Pakistan | 1.89 | 1.80 |
| 8. Beauvechain, Belgium | 2.01 | 1.77 |
| 9. Kleine Brogen, Belgium | 1.84 | 1.76 |
| 10. Skrydstru, Denmark | 2.28 | 1.98 |
| 11. Bodo, Norway | 1.42 | 1.38 |
| 12. Rygge, Norway | 2.24 | 2.19 |

Mean: 1.9 +/- 0.3

| FUEL (JP-8) | VISCOSITY SFTLA | (Cs @ -20°C) MONSANTO |
|---|---|---|
| Spec: 8.0 maximum | | |
| 1. Egypt | 3.50 | 3.40 |
| 2. Venezuela | N/A | 4.20 |
| 3. Leeuwarden, Netherlands | 4.46 | 4.10 |
| 4. Volkel, Netherlands | 3.73 | 3.44 |

TABLE A-13

HEAT OF COMBUSTION ANALYSES

| FUEL (JP-4) | NET HEAT OF COMBUSTION (MJ/kg) SFTLA | MONSANTO |
|---|---|---|
| Spec: 42.8 MJ/kg minimum | | |
| 1. Inshas, Egypt | N/A | 43.7 |
| 2. Inshas, Egypt | N/A | 43.3 |
| 3. Egypt | N/A | 43.3 |
| 4. King Fahad, Saudi Arabia | 43.6 | 43.4 |
| 5. King Aziz, Saudi Arabia | 43.6 | 43.4 |
| 6. Japan | 43.6 | 43.6 |
| 7. Pakistan | 43.6 | 43.6 |
| 8. Beauvechain, Belgium | 43.5 | 43.3 |
| 9. Kleine Brogen, Belgium | 43.6 | 43.5 |
| 10. Skrydstru, Denmark | 43.6 | 43.6 |
| 11. Bodo, Norway | 43.6 | 43.4 |
| 12. Rygge, Norway | 43.6 | 43.6 |
| Mean: | 43.6 +/- .03 | 43.3 +/- 0.14 |

| FUEL (JP-8) | NET HEAT OF COMBUSTION (MJ/kg) SFTLA | MONSANTO |
|---|---|---|
| Spec: 42.8 MJ/kg minimum | | |
| 1. Egypt | 43.4 | 43.3 |
| 2. Venezuela | N/A | 43.4 |
| 3. Leeuwarden, Netherlands | 43.4 | 43.4 |
| 4. Volkel, Netherlands | 43.3 | 43.2 |

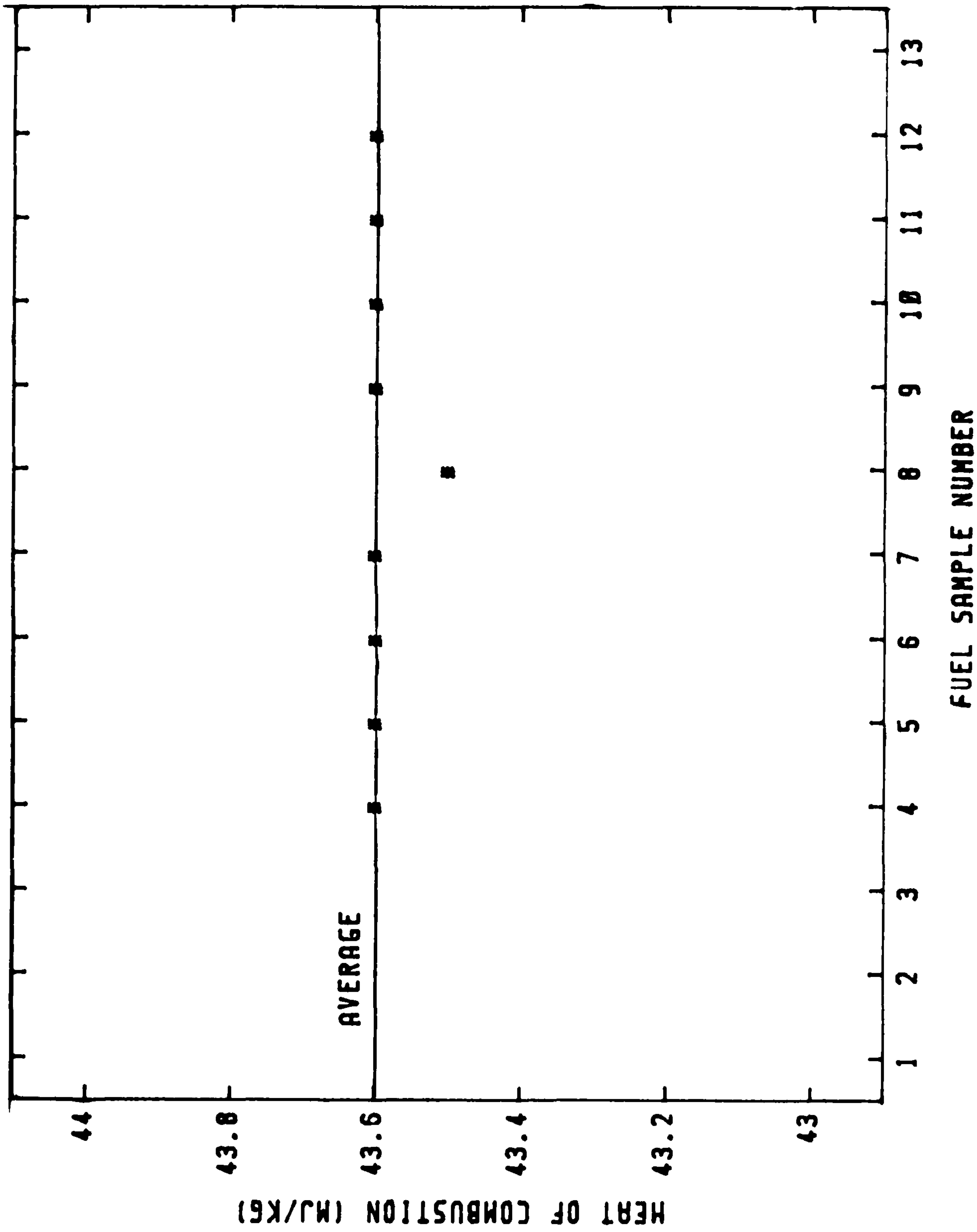


Figure A-7. Heat of Combustion

## TABLE A-14

## SMOKE POINT ANALYSES

| FUEL (JP-4) | SMOKE POINT, mm |
|---|---|
| Spec: 20 mm minimum | |
| 1. Inshas, Egypt | N/A |
| 2. Inshas, Egypt | N/A |
| 3. Egypt | N/A |
| 4. King Fahad, Saudi Arabia | 26 |
| 5. King Aziz, Saudi Arabia | 26 |
| 6. Japan | 27 |
| 7. Pakistan | 28 |
| 8. Beauvechain, Belgium | 27 |
| 9. Kleine Brogen, Belgium | 27 |
| 10. Skrydstru, Denmark | 27 |
| 11. Bodo, Norway | 28 |
| 12. Rygge, Norway | 28 |
| Mean: | 27 +/- 1 |

| FUEL (JP-8) | SMOKE POINT, mm |
|---|---|
| Spec: 19 mm minimum | |
| 1. Egypt | 22 |
| 2. Venezuela | N/A |
| 3. Leeuwarden, Netherlands | 25 |
| 4. Volkel, Netherlands | 22 |

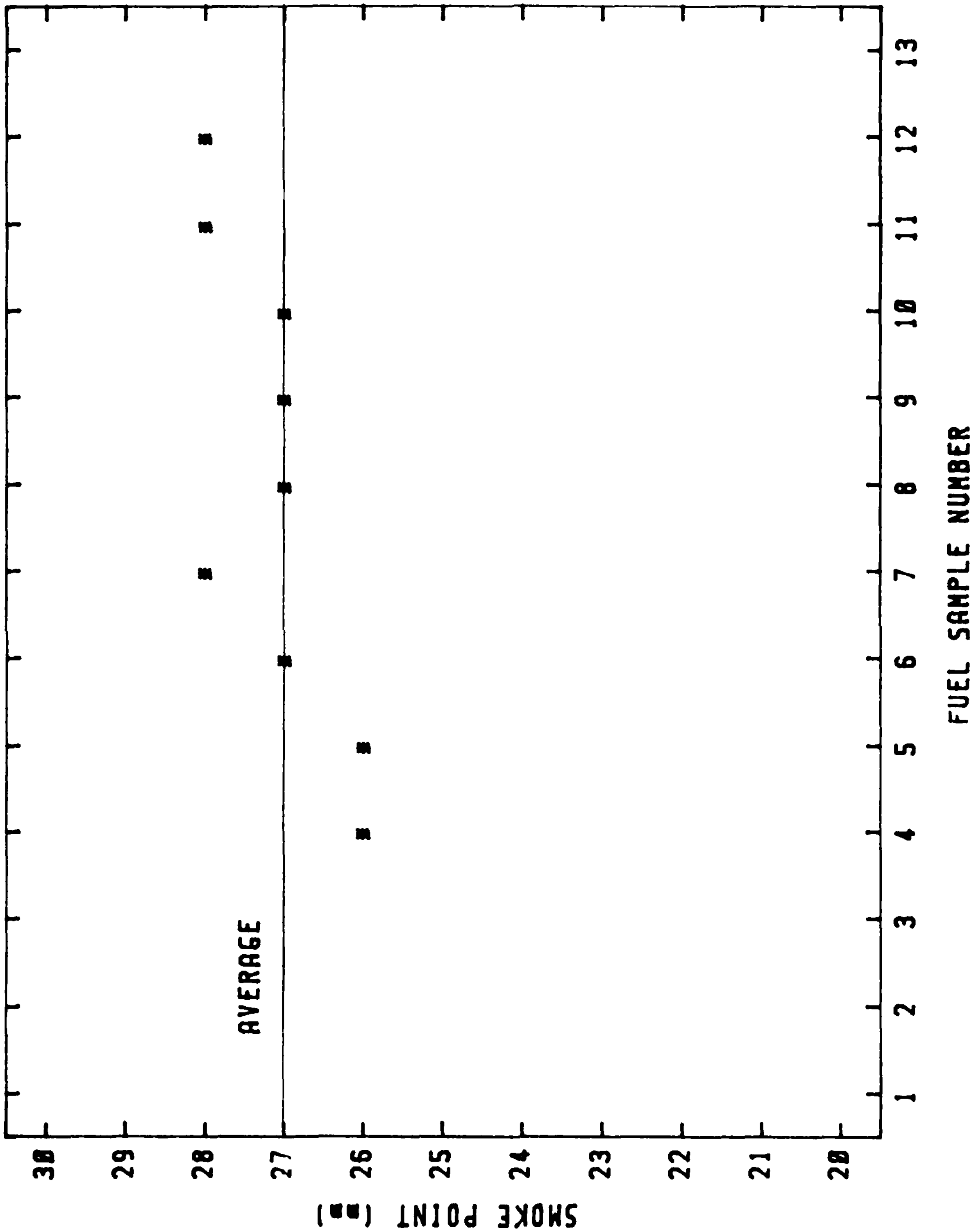


Figure A-8. Smoke Point

TABLE A-15

HYDROGEN CONTENT ANALYSES

| FUEL (JP-4) | SFTLA wt% H | POSF wt% H |
|---|---|---|
| Spec: 13.6 wt% minimum | | |
| 1. Inshas, Egypt | N/A | N/A |
| 2. Inshas, Egypt | N/A | N/A |
| 3. Egypt | N/A | 14.0 |
| 4. King Fahad, Saudi Arabia | 14.4 | 14.5 |
| 5. King Aziz, Saudi Arabia | 14.4 | 14.5 |
| 6. Japan | 14.5 | 14.4 |
| 7. Pakistan | 14.4 | 14.4 |
| 8. Beauvechain, Belgium | 14.3 | 14.3 |
| 9. Kleine Brogen, Belgium | 14.4 | 14.4 |
| 10. Skrydstru, Denmark | 14.4 | 14.3 |
| 11. Bodo, Norway | 14.2 | 14.1 |
| 12. Rygge, Norway | 14.3 | 14.2 |

Mean: 14.4 +/- .001

| FUEL (JP-8) | SFTLA wt% H | POSF wt% H |
|---|---|---|
| Spec: 13.5 wt% minimum | | |
| 1. Egypt | 14.0 | 14.10 |
| 2. Venezuela | N/A | 13.75 |
| 3. Leeuwarden, Netherlands | 14.0 | 14.03 |
| 4. Volkel, Netherlands | 13.8 | 13.74 |

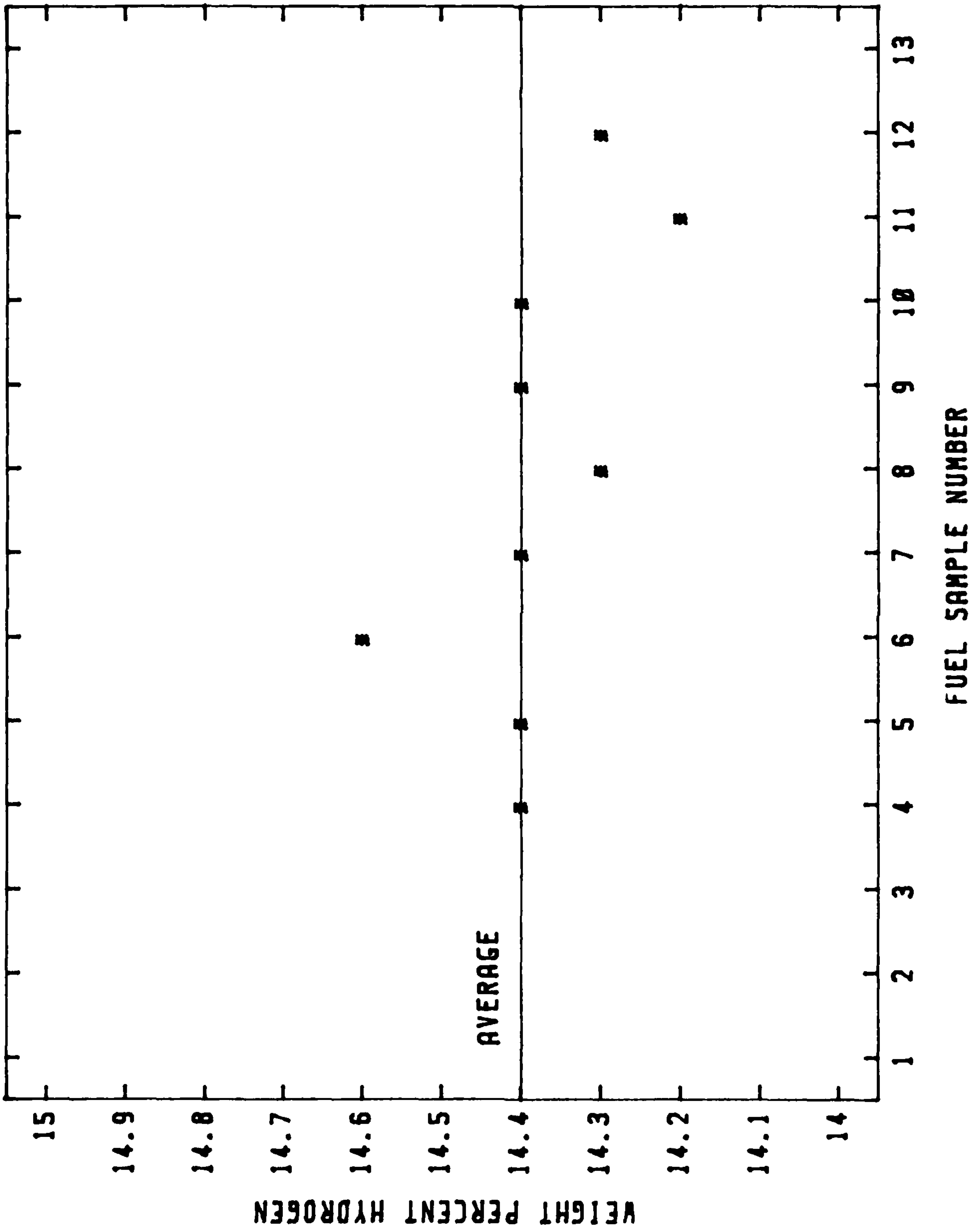


Figure A-9. Hydrogen Content

TABLE A-16

COPPER STRIP CORROSION ANALYSES

| FUEL (JP-4) | COPPER STRIP CORROSION |
|---|---|
| Spec: 1B maximum | |
| 1. Inshas, Egypt | N/A |
| 2. Inshas, Egypt | N/A |
| 3. Egypt | N/A |
| 4. King Fahad, Saudi Arabia | 1A |
| 5. King Aziz, Saudi Arabia | 1A |
| 6. Japan | 1A |
| 7. Pakistan | 1A |
| 8. Beauvechain, Belgium | 1A |
| 9. Kleine Brogen, Belgium | 1A |
| 10. Skrydstru, Denmark | 1A |
| 11. Bodo, Norway | 1A |
| 12. Rygge, Norway | 1A |

| FUEL (JP-8) | COPPER STRIP CORROSION |
|---|---|
| Spec: 1B maximum | |
| 1. Egypt | 1B |
| 2. Venezuela | N/A |
| 3. Leeuwarden, Netherlands | 1A |
| 4. Volkel, Netherlands | 1A |

TABLE A-17

THERMAL STABILITY ANALYSES

| FUEL (JP-4) | $\Delta$P mm Hg | PDC |
|---|---|---|
| Spec: $\Delta$P = 25 mm Hg maximum PDC < 3 | | |
| 1. Inshas, Egypt | N/A | N/A |
| 2. Inshas, Egypt | N/A | N/A |
| 3. Egypt | N/A | 1 |
| 4. King Fahad, Saudi Arabia | 0 | 1 |
| 5. King Aziz, Saudi Arabia | 0 | 1 |
| 6. Japan | 0 | 1 |
| 7. Pakistan | 0 | 1 |
| 8. Beauvechain, Belgium | 0 | 1 |
| 9. Kleine Brogen, Belgium | 0 | 1 |
| 10. Skrydstru, Denmark | 0 | 1 |
| 11. Bodo, Norway | 0 | 1 |
| 12. Rygge, Norway | 0 | 1 |
| Mean: | 0 | < 1 |

| FUEL (JP-8) | $\Delta$P mm Hg | PDC |
|---|---|---|
| Spec: $\Delta$P = 25 mm Hg maximum PDC < 3 | | |
| 1. Egypt | N/A | N/A |
| 2. Venezuela | N/A | N/A |
| 3. Leeuwarden, Netherlands | 0 | 1 |
| 4. Volkel, Netherlands | 0 | 1 |

TABLE A-18

EXISTENT GUM ANALYSES

| FUEL (JP-4) | EXISTENT GUM (mg/ml) |
|---|---|
| Spec: 7.0 mg/100 ml maximum | |
| 1. Inshas, Egypt | N/A |
| 2. Inshas, Egypt | N/A |
| 3. Egypt | N/A |
| 4. King Fahad, Saudi Arabia | 0.0 |
| 5. King Aziz, Saudi Arabia | 0.0 |
| 6. Japan | 0.4 |
| 7. Pakistan | 1.0 |
| 8. Beauvechain, Belgium | 0.6 |
| 9. Kleine Brogen, Belgium | 1.4 |
| 10. Skrydstru, Denmark | 0.4 |
| 11. Bodo, Norway | 0.2 |
| 12. Rygge, Norway | 0.6 |
| | Mean: 0.5 +/- 0.5 |

| FUEL (JP-8) | EXISTENT GUM (mg/ml) |
|---|---|
| Spec: 7.0 mg/100 ml maximum | |
| 1. Egypt | 0.0 |
| 2. Venezuela | N/A |
| 3. Leeuwarden, Netherlands | 0.4 |
| 4. Volkel, Netherlands | 2.6 |

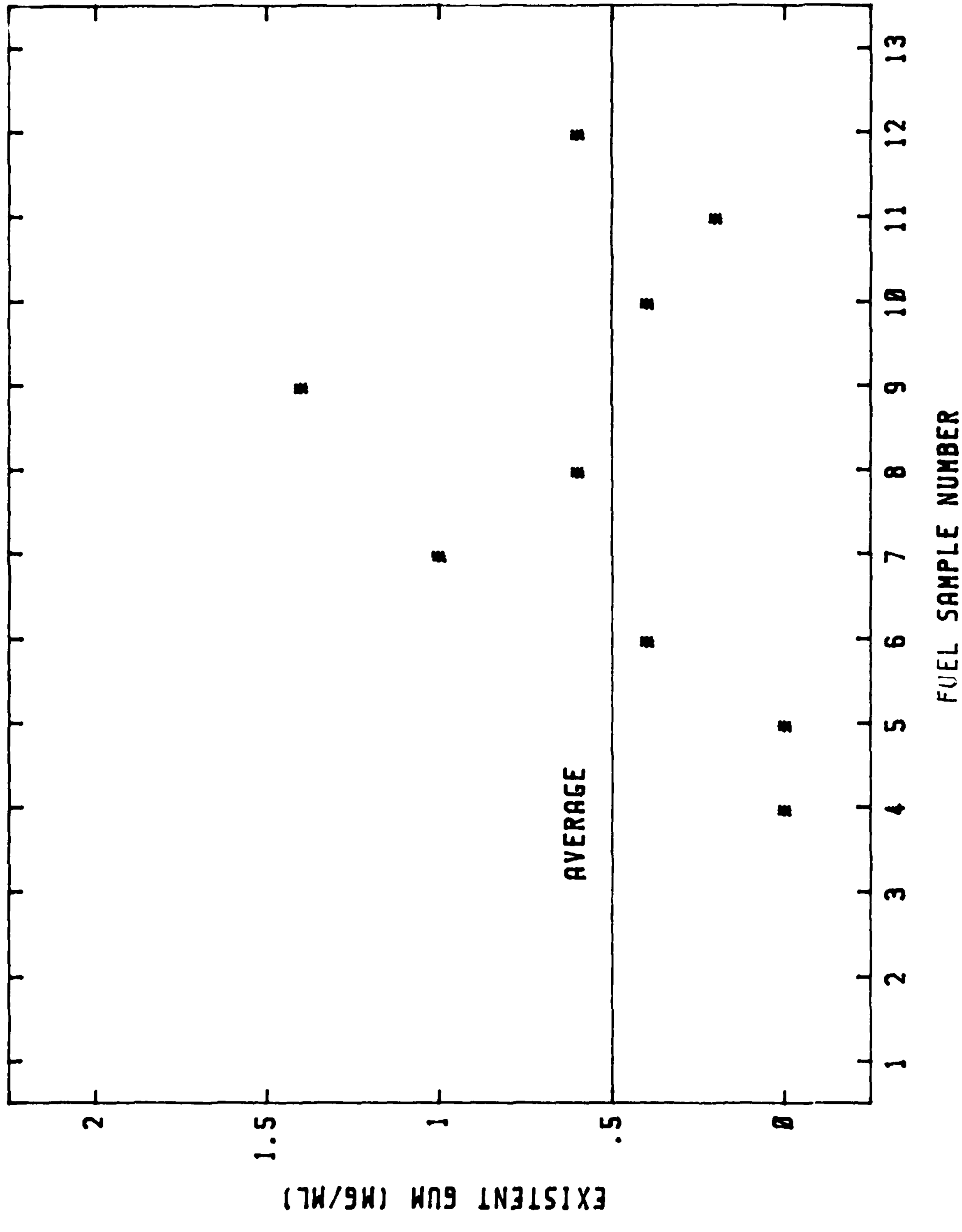


Figure A-10. Existent Gum

TABLE A-19

VOLUME PERCENT FUEL SYSTEM ICING INHIBITOR ANALYSES

Spec: 0.10 minimum, 0.15 maximum

| | FUEL (JP-4) | VOL % FSII |
|---|---|---|
| 1. | Inshas, Egypt | N/A |
| 2. | Inshas, Egypt | N/A |
| 3. | Egypt | N/A |
| 4. | King Fahad, Saudi Arabia | 0.00 |
| 5. | King Aziz, Saudi Arabia | 0.00 |
| 6. | Japan | 0.16 |
| 7. | Pakistan | 0.01 |
| 8. | Beauvechain, Belgium | 0.16 |
| 9. | Kleine Brogen, Belgium | 0.14 |
| 10. | Skrydstru, Denmark | 0.15 |
| 11. | Bodo, Norway | 0.17 |
| 12. | Rygge, Norway | 0.17 |

Mean: 0.11 +/- 0.08

Spec: 0.10 minimum, 0.15 maximum

| | FUEL (JP-8) | VOL % FSII |
|---|---|---|
| 1. | Egypt | 0.00 |
| 2. | Venezuela | N/A |
| 3. | Leeuwarden, Netherlands | 0.13 |
| 4. | Volkel, Netherlands | 0.14 |

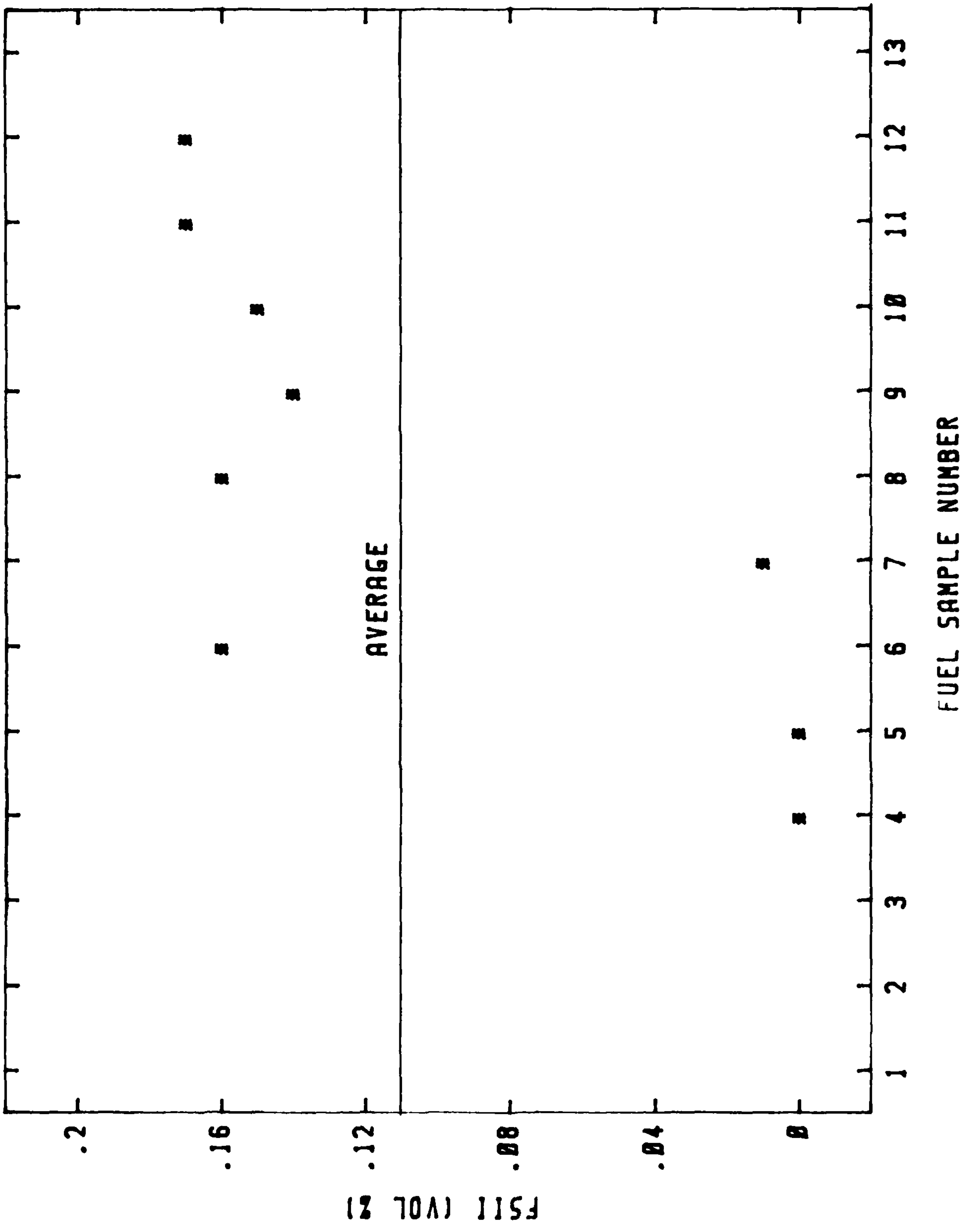


Figure A-11. Fuel System Icing Inhibitor

# APPENDIX B

# CHARACTERIZATION ANALYSES

TABLE B-1

PHYSICAL PROPERTIES AS A FUNCTION OF TEMPERATURE

| | Vapor pressure (mm Hg) | Kinematic viscosity (centistokes) | Density ($g/cm^3$) | Surface tension (dynes/cm) |
|---|---|---|---|---|
| INSHAS #1 | | | | |
| -30.1 F | - [a] | - | - | - [b] |
| -20 F | 2 | 4.040 | 0.8244 | 30.4 |
| - 4 F | - | - | - | - |
| 32 F | 7 | 2.096 | 0.8020 | 27.9 |
| 59 F | - | - | 0.7905 | - |
| 70 F | 13 | 1.460 | 0.7857 | 25.9 |
| 100 F | 21 | 1.152 | 0.7728 | 24.4 |
| 140 F | 38 | 0.877 | 0.7557 | 22.5 |
| INSHAS #2 | | | | |
| -30.1 F | - | - | - | - [b] |
| -20 F | 1.2 [a] | 3.923 | 0.8210 | 30.1 |
| - 4 F | - | - | - | - |
| 32 F | 5 | 2.046 | 0.8004 | 27.7 |
| 59 F | - | - | 0.7898 | - |
| 70 F | 10 | 1.436 | 0.7855 | 25.9 |
| 100 F | 17 | 1.128 | 0.7736 | 24.4 |
| 140 F | 33 | 0.865 | 0.7578 | 22.7 |
| EGYPT JP-4 | | | | |
| -30.1 F | - | 4.425 | - | - [b] |
| -20 F | 0.7 [a] | 3.775 | 0.8200 | 29.9 |
| - 4 F | - | 2.937 | - | - |
| 32 F | 3.3 | 1.996 | 0.7993 | 27.4 |
| 59 F | - | - | 0.7885 | - |
| 70 F | 8.2 | 1.395 | 0.7839 | 25.8 |
| 100 F | 15.5 | 1.129 | 0.7713 | 24.3 |
| 140 F | 34 | 0.853 | 0.7546 | 22.4 |

[a] Value determined by extrapolation of Log P versus 1/T vapor pressure relationship.

[b] Obtained by linear regression extrapolation of data.

TABLE B-1 (Continued)

| | Vapor pressure (mm Hg) | Kinematic viscosity (centistokes) | Density ($g/cm^3$) | Surface tension (dynes/cm) |
|---|---|---|---|---|
| KING FAHAD | | | | |
| -30.1 F | - | 2.4557 | - | - |
| -20 F | 8.3[a] | 2.1669 | 0.7920 | 28.9[b] |
| - 4 F | - | 1.8133 | - | - |
| 32 F | 35.5 | 1.3327 | 0.7696 | 26.1 |
| 59 F | - | - | 0.7580 | - |
| 70 F | 80 | 0.9968 | 0.7533 | 24.0 |
| 100 F | 144 | 0.8234 | 0.7404 | 22.4 |
| 140 F | 296 | 0.6587 | 0.7232 | 20.2 |
| KING AZIZ | | | | |
| -30.1 F | - | 2.4995 | - | - |
| -20 F | 7.4[a] | 2.2111 | 0.7901 | 28.9[b] |
| - 4 F | - | 1.8464 | - | - |
| 32 F | 38 | 1.3503 | 0.7689 | 26.2 |
| 59 F | - | - | 0.7579 | - |
| 70 F | 82 | 1.0113 | 0.7534 | 24.2 |
| 100 F | 155 | 0.8325 | 0.7412 | 22.6 |
| 140 F | 335 | 0.6685 | 0.7249 | 20.5 |
| JAPAN | | | | |
| -30.1 F | - | 2.2620 | - | - |
| -20 F | 9[a] | 2.0192 | 0.7892 | 28.3[b] |
| - 4 F | - | 1.6958 | - | - |
| 32 F | 34 | 1.2640 | 0.7690 | 25.8 |
| 59 F | - | - | 0.7577 | - |
| 70 F | 76 | 0.9499 | 0.7530 | 24.0 |
| 100 F | 132 | 0.7837 | 0.7395 | 22.6 |
| 140 F | 262 | 0.6303 | 0.7217 | 20.6 |

[a] Value determined by extrapolation of Log P versus 1/T vapor pressure relationship.

[b] Obtained by linear regression extrapolation of data.

TABLE B-1 (Continued)

| | Vapor pressure (mm Hg) | Kinematic viscosity (centistokes) | Density ($g/cm^3$) | Surface tension (dynes/cm) |
|---|---|---|---|---|
| EGYPT | | | | |
| -30.1 F | - | 5.03 | - | - |
| -20 F | 1.5 [a] | 4.360 | 0.8242 | 30.6 [b] |
| - 4 F | - | - | - | - |
| 32 F | 5.2 | 3.333 | 0.8038 | 28.0 |
| 59 F | - | 2.123 | 0.7925 | - |
| 70 F | 11 | 1.493 | 0.7881 | 26.1 |
| 100 F | 18 | 1.172 | 0.7759 | 24.6 |
| 140 F | - | - | - | - |
| VENEZUELA | | | | |
| -30.1 F | - [a] | 2.2036 | - | - [b] |
| -20 F | 8.4 | 1.9598 | 0.7893 | 28.1 |
| - 4 F | - | - | - | - |
| 32 F | 34 | 1.2327 | 0.7672 | 25.6 |
| 59 F | - | - | 0.7559 | - |
| 70 F | 76 | 0.9280 | 0.7510 | 23.7 |
| 100 F | 136 | 0.7701 | 0.7382 | 22.3 |
| 140 F | 269 | 0.6191 | 0.7212 | 20.3 |
| LEEUWARDEN | | | | |
| -30.1 F | - [a] | 6.4397 | - | - [b] |
| -20 F | 4.4 | 5.4077 | 0.8295 | 31.6 |
| - 4 F | - | 4.1337 | - | - |
| 32 F | 9 | 2.6412 | 0.8098 | 28.8 |
| 59 F | - | - | 0.7984 | - |
| 70 F | 15 | 1.7432 | 0.7934 | 26.7 |
| 100 F | 21.5 | 1.3587 | 0.7825 | 25.1 |
| 140 F | 33.5 | 1.0246 | 0.7660 | 22.9 |

[a] Value determined by extrapolation of Log P versus 1/T vapor pressure relationship.

[b] Obtained by linear regression extrapolation of data.

TABLE B-1 (Continued)

| | Vapor pressure (mm Hg) | Kinematic viscosity (centistokes) | Density ($g/cm^3$) | Surface tension (dynes/cm) |
|---|---|---|---|---|
| PAKISTAN | | | | |
| -30.1 F | - | 7.6082 | - | - |
| -20 F | 5.8 [a] | 6.1395 | 0.8432 | 32.5 [b] |
| - 4 F | - | - | - | - |
| 32 F | 12 | 2.8664 | 0.8229 | 29.7 |
| 59 F | - | - | 0.8132 | - |
| 70 F | 18 | 1.8852 | 0.8080 | 27.6 |
| 100 F | 25 | 1.4388 | 0.7963 | 25.9 |
| 140 F | 36 | 1.0752 | 0.7799 | 23.7 |
| BEAUVECHAIN | | | | |
| -30.1 F | - | 2.3460 | - | - |
| -20 F | 8.2 [a] | 2.1091 | 0.7993 | 29.0 [b] |
| - 4 F | - | 1.7714 | - | - |
| 32 F | 34 | 1.3080 | 0.7771 | 26.3 |
| 59 F | - | - | 0.7656 | - |
| 70 F | 78 | 0.9669 | 0.7609 | 24.3 |
| 100 F | 138 | 0.8060 | 0.7481 | 22.7 |
| 140 F | 277 | 0.6461 | 0.7310 | 20.6 |
| KLEINE BROGEN | | | | |
| -30.1 F | - | 2.3508 | - | - |
| -20 F | 10.3 [a] | 2.0976 | 0.7940 | 28.6 [b] |
| - 4 F | - | 1.7578 | - | - |
| 32 F | 32.5 | 1.2938 | 0.7720 | 25.9 |
| 59 F | - | - | 0.7606 | - |
| 70 F | 75 | 0.9678 | 0.7560 | 23.9 |
| 100 F | 137 | 0.8054 | 0.7443 | 22.3 |
| 140 F | 275 | 0.6466 | 0.7264 | 20.2 |

[a] Value determined by extrapolation of Log P versus 1/T vapor pressure relationship.

[b] Obtained by linear regression extrapolation of data.

TABLE B-1 (Continued)

| | Vapor pressure (mm Hg) | Kinematic viscosity (centistokes) | Density (g/cm $^3$) | Surface tension (dynes/cm) |
|---|---|---|---|---|
| SKRYDSTRU | | | | |
| -30.1 F | - | 2.7255 | - | - |
| -20 F | 15 [a] | 2.4135 | 0.8009 | 29.0 [b] |
| - 4 F | - | 1.9835 | - | - |
| 32 F | 47.5 | 1.4392 | 0.7789 | 26.3 |
| 59 F | - | - | 0.7675 | - |
| 70 F | 95 | 1.0577 | 0.7628 | 24.3 |
| 100 F | 152 | 0.8709 | 0.7502 | 22.7 |
| 140 F | 272 | 0.6953 | 0.7333 | 20.6 |
| BODO | | | | |
| -30.1 F | N/A | 1.7956 | - | - |
| -20 F | N/A | 1.6354 | 0.7916 | 29.2 [b] |
| - 4 F | N/A | 1.3768 | - | - |
| 32 F | N/A | 1.0508 | 0.7687 | 26.3 |
| 59 F | N/A | - | 0.7567 | - |
| 70 F | N/A | 0.8178 | 0.7319 | 24.1 |
| 100 F | N/A | 0.6751 | 0.7386 | 22.4 |
| 140 F | N/A | 0.5555 | 0.7210 | 20.1 |
| RYGGE | | | | |
| -30.1 F | N/A | 3.0575 | - | - |
| -20 F | N/A | 2.6859 | 0.8066 | 29.6 [b] |
| - 4 F | N/A | 2.1880 | - | - |
| 32 F | N/A | 1.5555 | 0.7857 | 27.1 |
| 59 F | N/A | - | 0.7740 | - |
| 70 F | N/A | 1.1414 | 0.7694 | 25.3 |
| 100 F | N/A | 0.9171 | 0.7570 | 23.9 |
| 140 F | N/A | 0.7229 | 0.7405 | 22.0 |

[a] Value determined by extrapolation of Log P versus 1/T vapor pressure relationship.

[b] Obtained by linear regression extrapolation of data.

TABLE B-1 (Concluded)

| | Vapor pressure (mm Hg) | Kinematic viscosity (centistokes) | Density ($g/cm^3$) | Surface tension (dynes/cm) |
|---|---|---|---|---|
| VOLKEL | | | | |
| -30.1 F | -[a] | 6.4397 | - | - |
| -20 F | 10 | 5.4077 | 0.8295 | 31.6[b] |
| - 4 F | - | 4.1337 | - | - |
| 32 F | 20.5 | 2.6412 | 0.8098 | 28.8 |
| 59 F | - | - | 0.7984 | - |
| 70 F | 15 | 1.7432 | 0.7934 | 26.7 |
| 100 F | 21.5 | 1.3587 | 0.7825 | 25.1 |
| 140 F | 33.5 | 1.0246 | 0.7660 | 22.9 |

[a]Value determined by extrapolation of Log P versus 1/T vapor pressure relationship.
[b]Obtained by linear regression extrapolation of data.

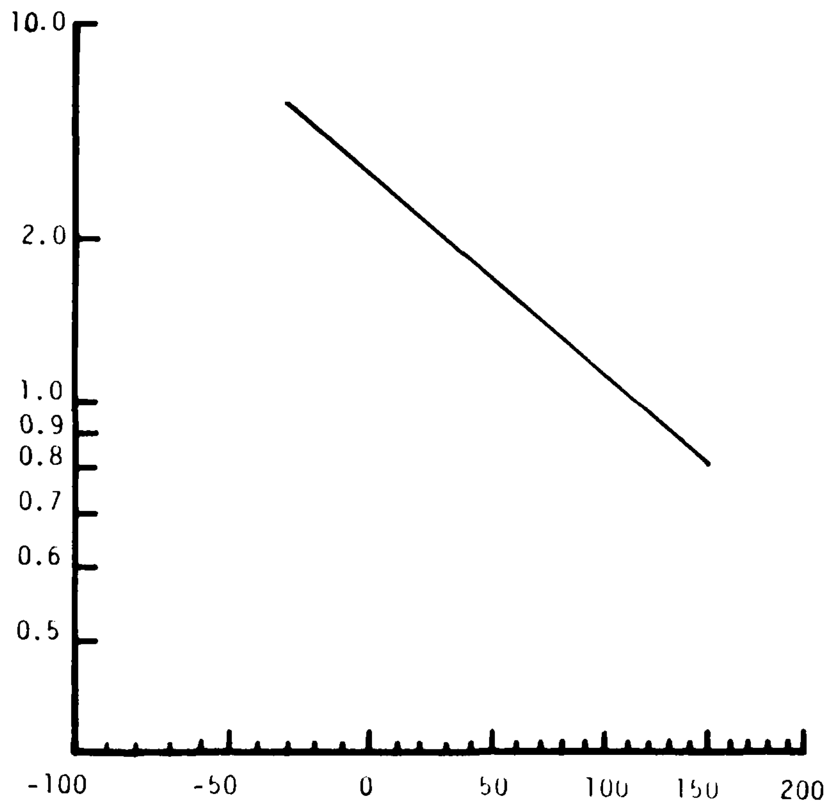


Figure B-1. Viscosity vs Temperature Plot for Inshas #1 Sample

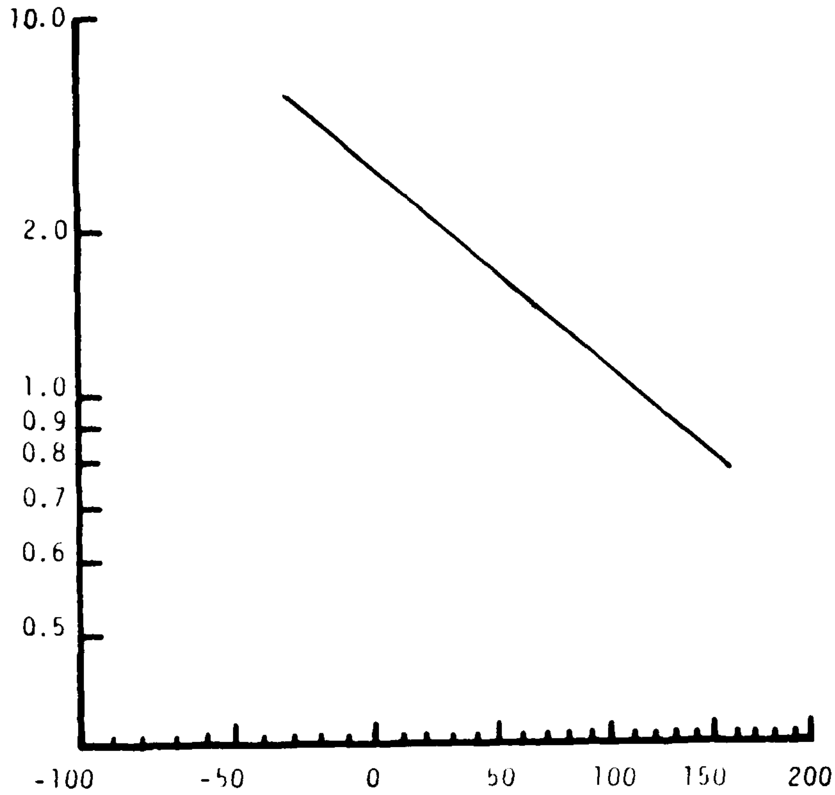


Figure B-2. Viscosity vs Temperature Plot for Inshas #2 Sample

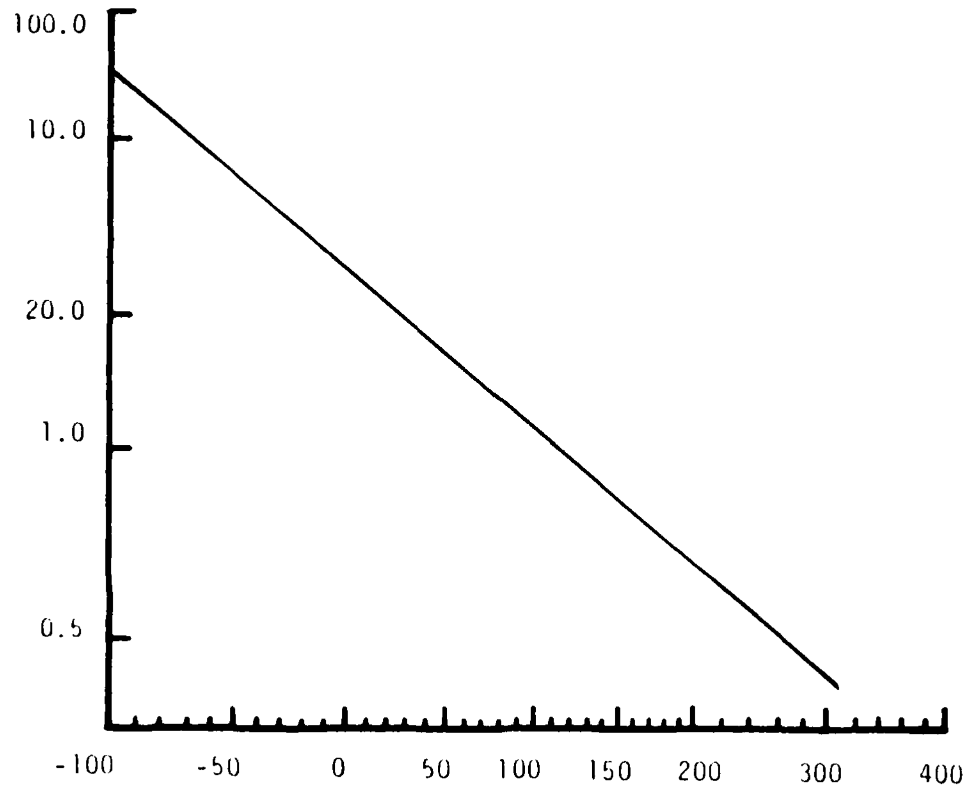


Figure B-3. Viscosity vs Temperature Plot for Egypt JP-4 Sample

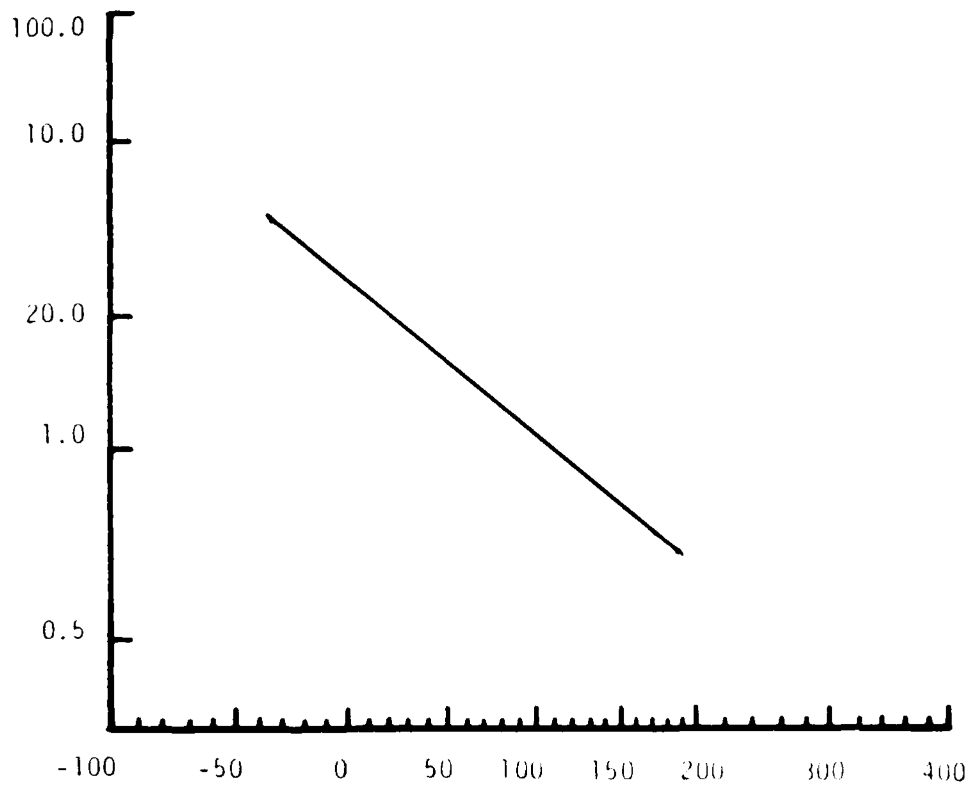


Figure B-4. Viscosity vs Temperature Plot for King Fahad Sample

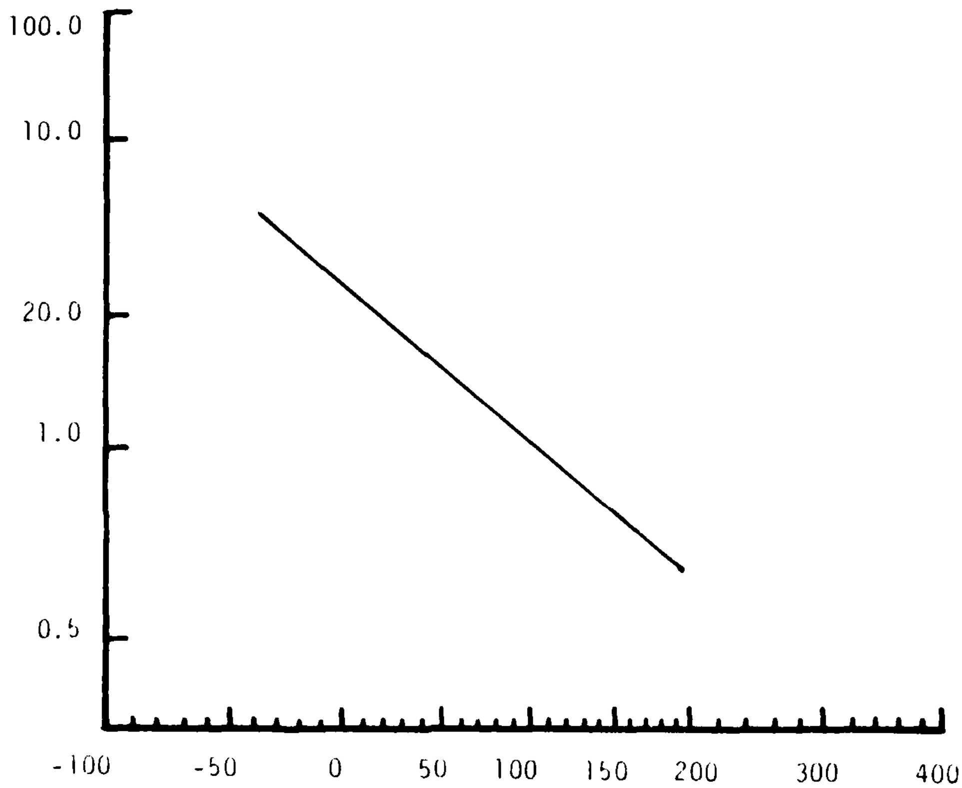


Figure B-5. Viscosity vs Temperature Plot for King Aziz Sample

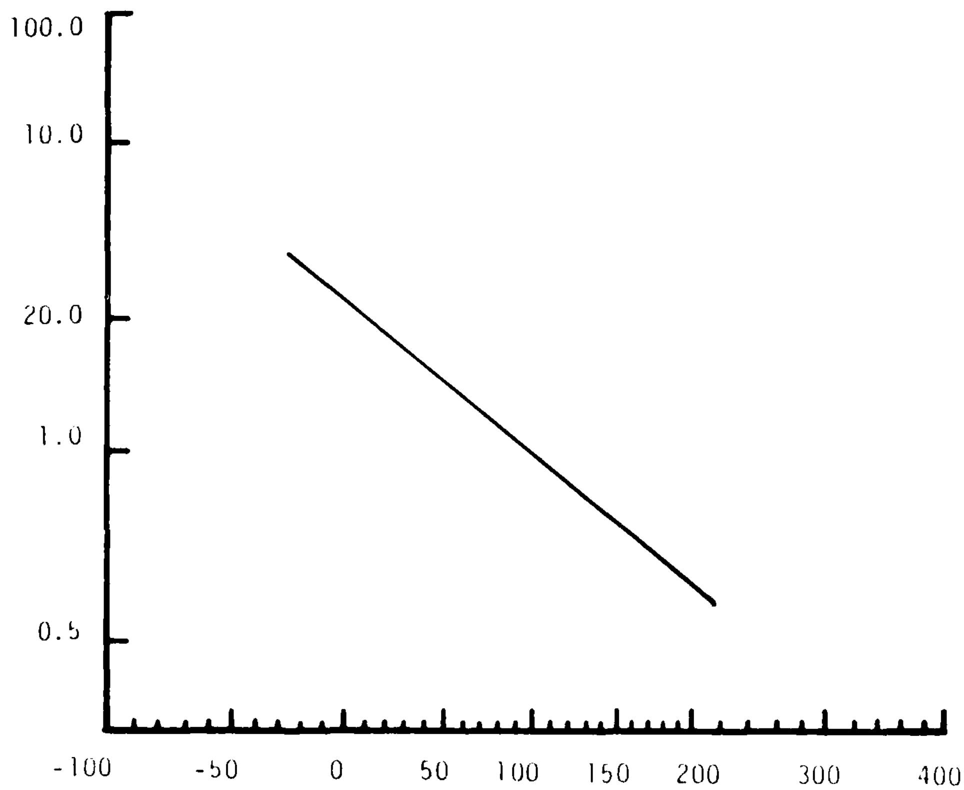


Figure B-6. Viscosity vs Temperature Plot for Japan Sample

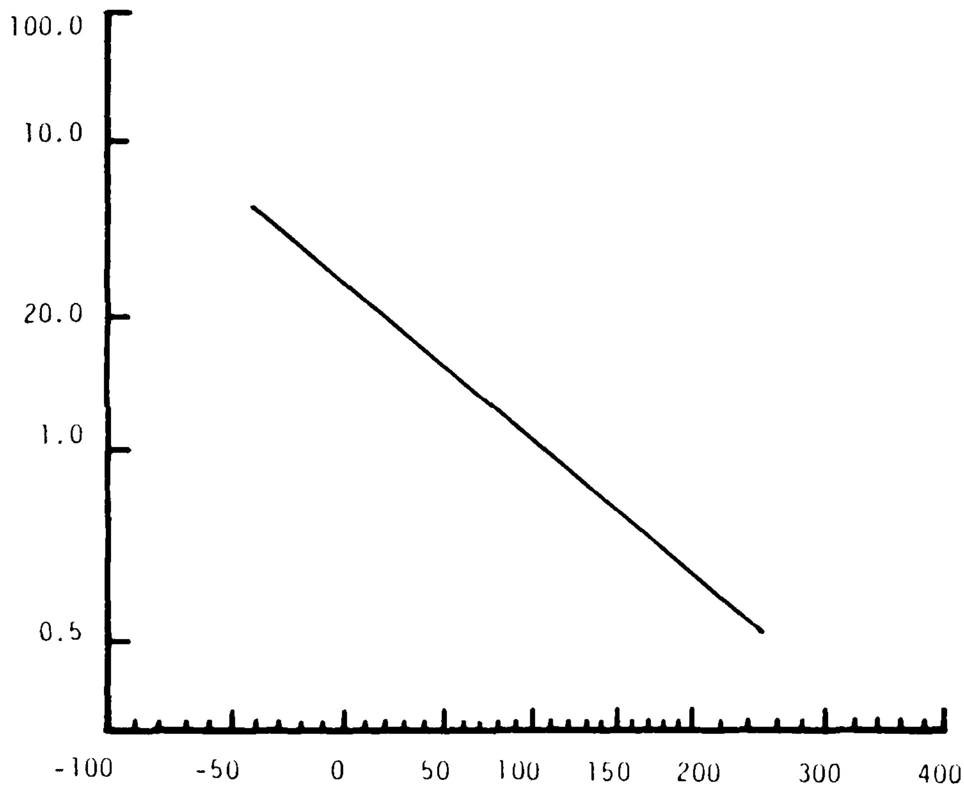


Figure B-7. Viscosity vs Temperature Plot for Beauvechain Sample

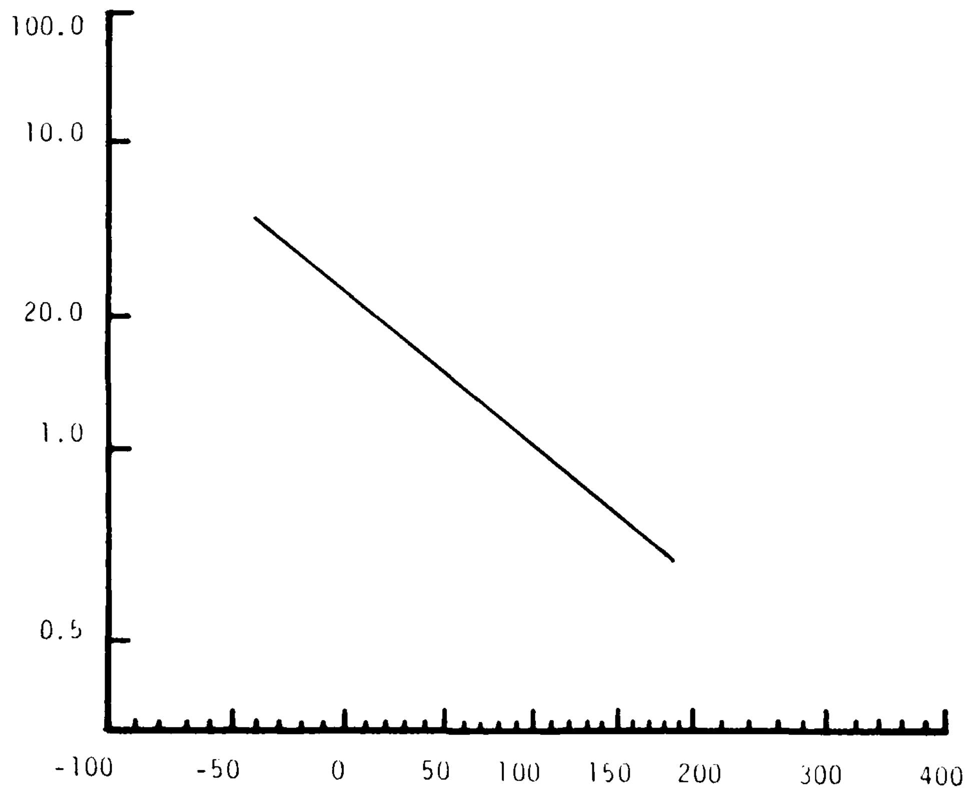


Figure B-8. Viscosity vs Temperature Plot for Kleine Brogen Sample

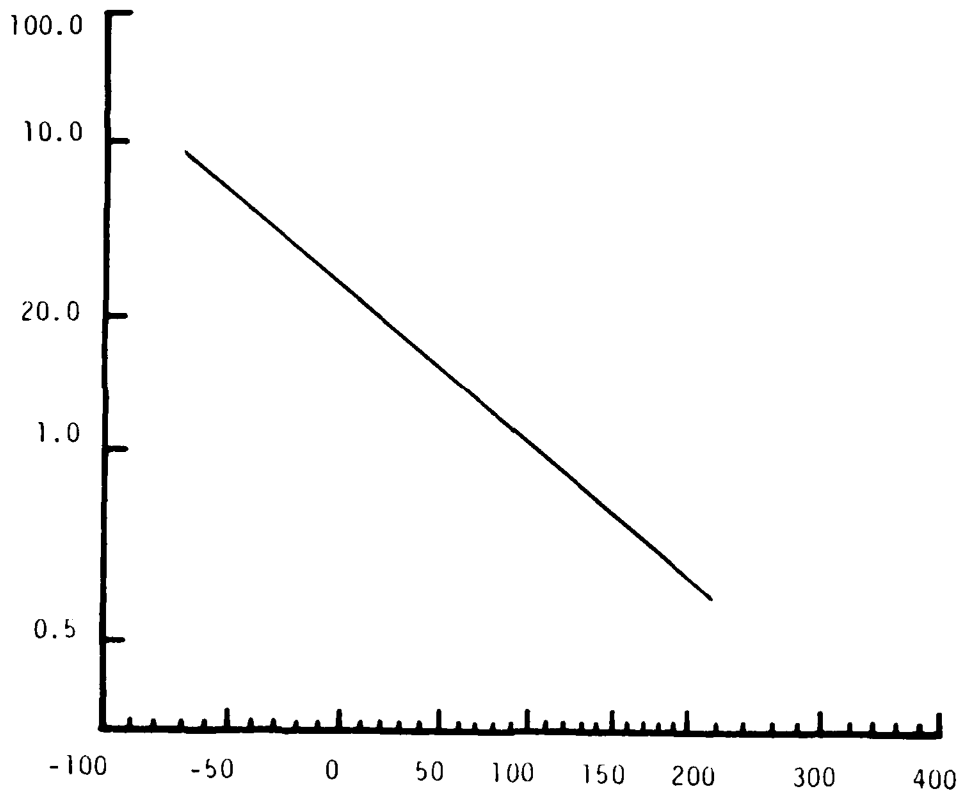


Figure B-9. Viscosity vs Temperature Plot for Skrydstru Sample

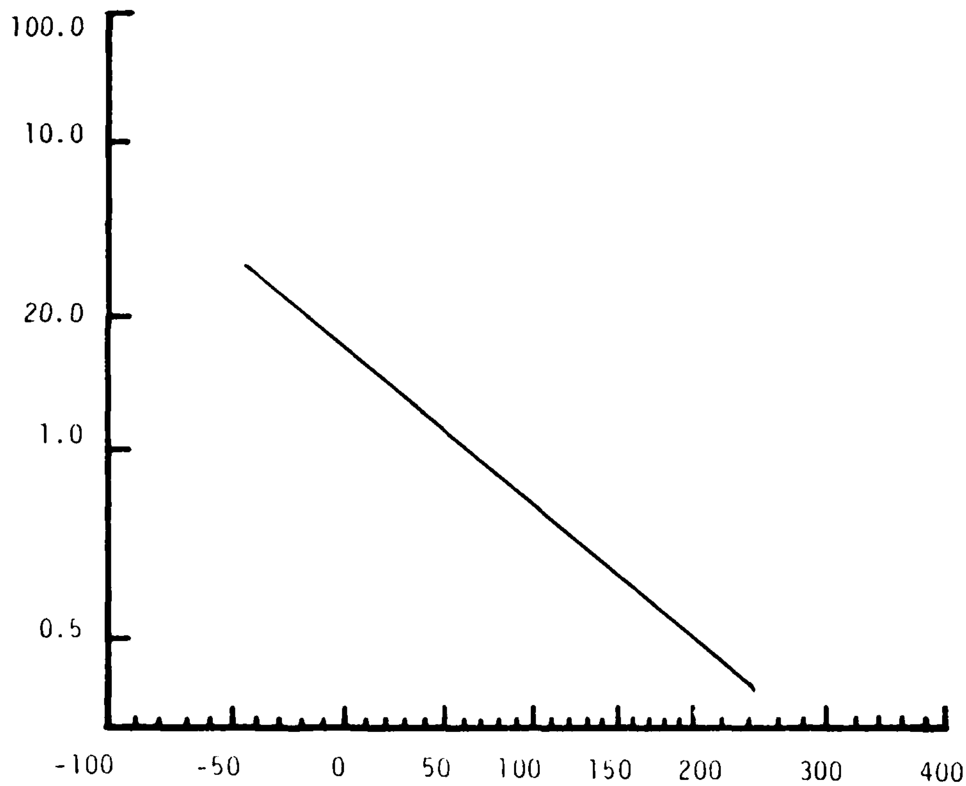


Figure B-10. Viscosity vs Temperature Plot for Bodo Sample

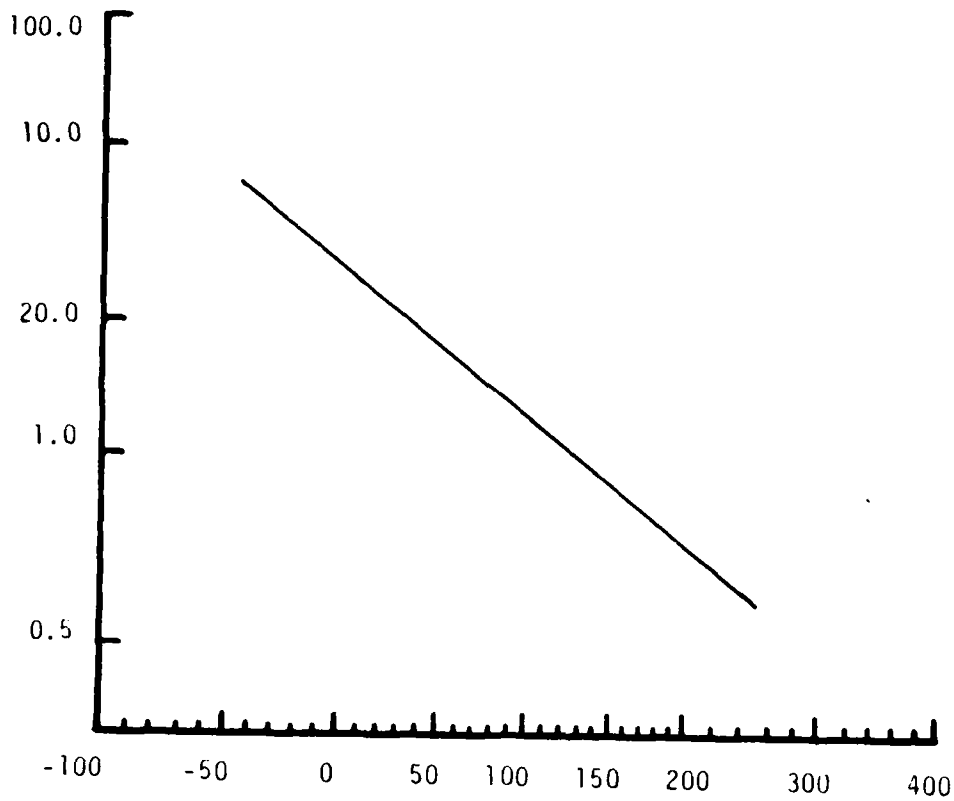


Figure B-11. Viscosity vs Temperature Plot for Rygge Sample

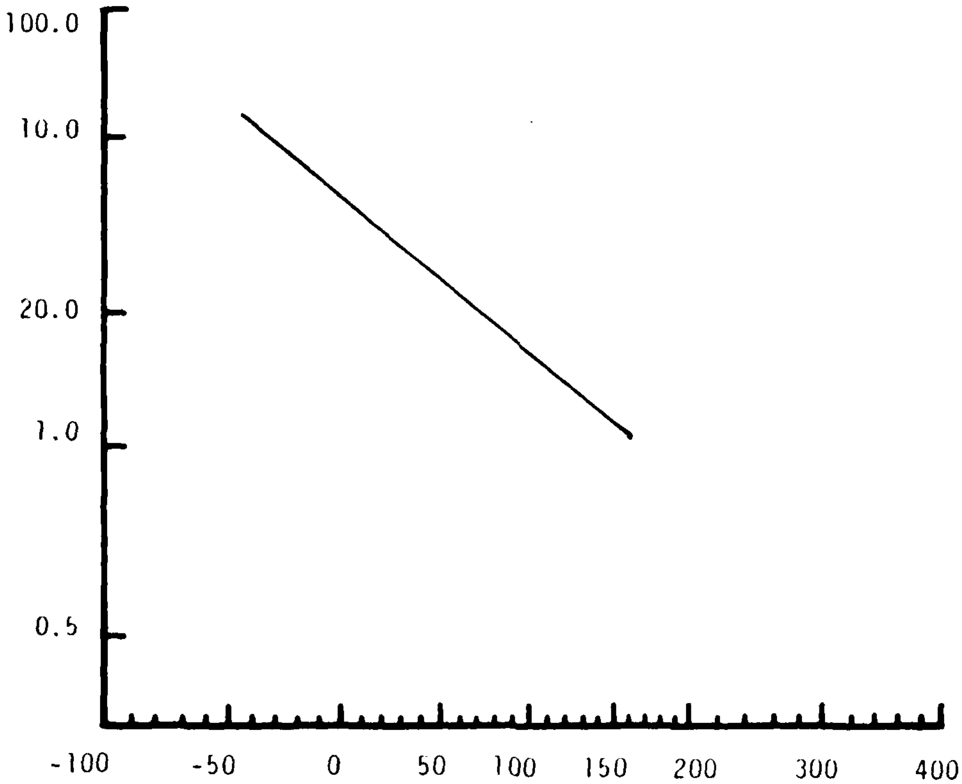


Figure B-12. Viscosity vs Temperature Plot for Egypt JP-8 Sample

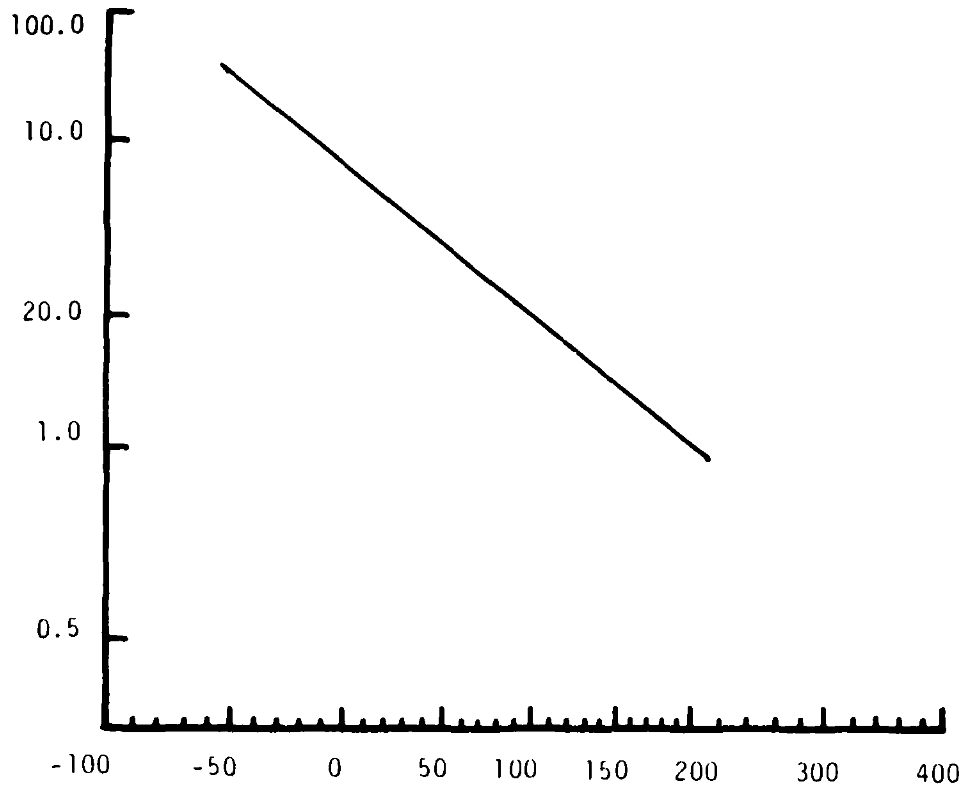


Figure B-13. Viscosity vs Temperature Plot for Leeuwarden Sample

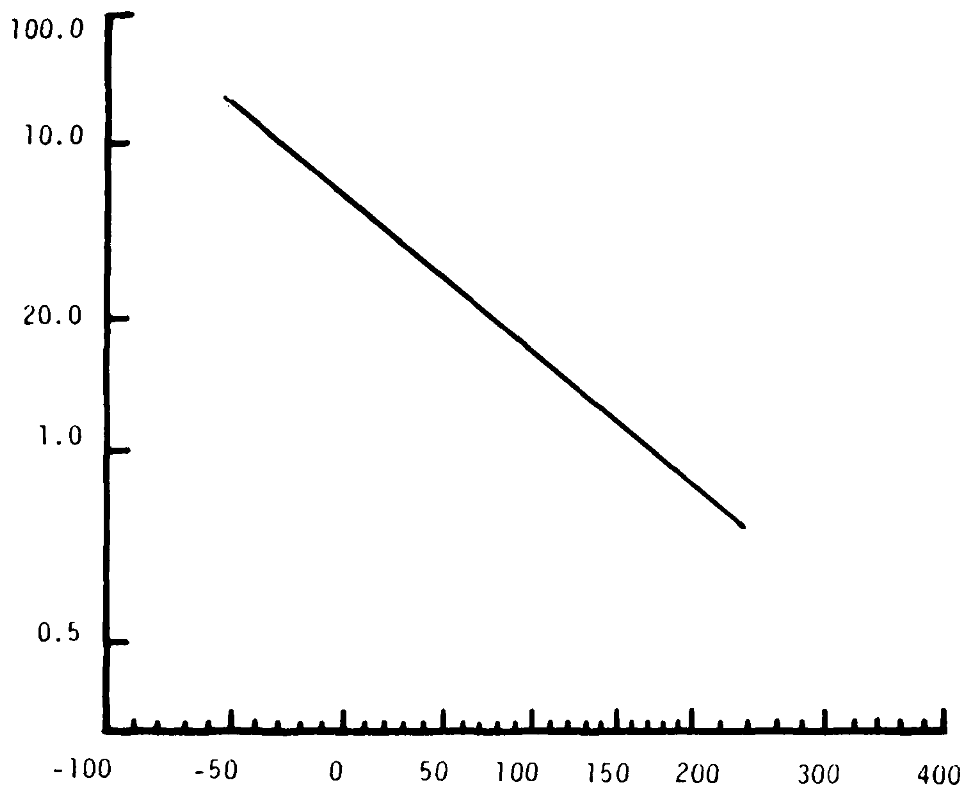


Figure B-14. Viscosity vs Temperature Plot for Volkel Sample

TABLE B-2

COMPARISON OF TYPICAL JP-4 AND AVERAGED F100 JP-4 SAMPLES
VAPOR PRESSURE AS A FUNCTION OF TEMPERATURE

| Temperature °F (°C) | Vapor Pressure (mm Hg) Typical JP-4 | F100 US | F100 Foreign |
|---|---|---|---|
| -20 (-28.9) | no data | 7 | 6.79 |
| 32 (0) | 23.25 [a] | 30.8 | 24.88 |
| 70 (21.1) | 81.01 | 72.6 | 53.52 |
| 100 (37.8) | 126.00 | 133.0 | 93.65 |
| 140 (60) | 283.50 | 276.9 | 185.80 |

[a] Obtained by extrapolation

TABLE B-3

COMPARISON OF TYPICAL JP-4 AND AVERAGED F100 JP-4 SAMPLES
KINEMATIC VISCOSITY AS A FUNCTION OF TEMPERATURE

| Temperature °F (°C) | Kinematic Viscosity Cs Typical JP-4 | F100 US | F100 Foreign |
|---|---|---|---|
| -30.1 (-34.5) | 2.3 | 2.21 | 3.15 |
| -20 (-28.8) | 2.1 | 1.96 | 2.93 |
| - 4 (-20) | 1.7 | 1.65 | 2.02 |
| 32 (0) | 1.23 | 1.22 | 1.63 |
| 70 (21.1) | 0.56 | 0.932 | 1.17 |
| 100 (37.8) | 0.44 | 0.762 | 0.95 |
| 140 (60) | 0.40 | 0.616 | 0.74 |

TABLE B-4

COMPARISON OF TYPICAL JP-4 AND AVERAGED F100 JP-4 SAMPLES
DENSITY AS A FUNCTION OF TEMPERATURE

| Temperature °F (°C) | Density (g/cm ) Typical JP- | F100 US | F100 Foreign |
|---|---|---|---|
| -20 (-28.8) | 0.797 | 0.796 | 0.806 |
| 32 (0) | 0.775 | 0.774 | 0.786 |
| 59 (15) | 0.764 | 0.763 | 0.776 |
| 70 (21.1) | 0.758 | 0.759 | 0.768 |
| 100 (37.8) | 0.698 | 0.745 | 0.756 |
| 140 (60) | not avail. | 0.727 | 0.739 |

[a] Obtained by extrapolation

TABLE B-5

COMPARISON OF TYPICAL JP-4 AND AVERAGE F100 JP-4 SAMPLES
SURFACE TENSION AS A FUNCTION OF TEMPERATURE

| Temperature °F (°C) | Surface Tension (dyne/cm) Typical JP-4 | F100 US | F100 Foreign |
|---|---|---|---|
| -20 (-28.8) | 25.9 | 28.3 | 29.5 |
| - 4 (-20) | 25.2 | 25.6 | 26.9 |
| 70 (21.1) | 21.7 | 23.6 | 24.9 |
| 100 (37.8) | 20.3 | 22.0 | 23.4 |
| 140 (60) | 18.4 | 20.0 | 21.3 |

TABLE B-6

THERMAL CONDUCTIVITY ANALYSES

| Sample | Thermal Conductivity (Watt/meter Kelvin) 0 °C | 20 °C | 40 °C |
|---|---|---|---|
| Inshas #1 | 0.123 +/- 2.36% [b] | 0.121 +/- 2.48% | 0.116 +/- 3.46% |
| Inshas #2 | 0.123 +/- 2.51% | 0.120 +/- 3.00% | 0.115 +/- 3.83% |
| Toluene (standard) | 0.140 +/- 3.71% | 0.1317 +/- 2.12% | 0.1253 +/- 3.05% |
| Toluene (literature value [a]) | 0.1366 | 0.1308 | 0.1250 |

[a]Literature values from Venart & Mani, Can. J. Chem. 49, 2468 (1971).

[b]Standard deviation of 6-8 measurements made at each temperature.

TABLE B-7

COMPARISON OF TYPICAL JP-4 AND EGYPTIAN F100 JP-4 SAMPLES THERMAL CONDUCTIVITY

| Temperature F (°C) | Thermal Conductivity (watt/meter °K) Typical | US F100 Samples | Egyptian Samples |
|---|---|---|---|
| 0 | .1188 | 0.122 | 0.123 |
| 20 | .1155 | 0.117 | 0.121 |
| 40 | .1118 | 0.112 | 0.116 |

## TABLE B-8

## SPECIFIC HEAT ANALYSES

| Sample | Specific Heat (cal/g/°C) 35°C | 45°C | 55°C | 65°C | 75°C | 85°C |
|---|---|---|---|---|---|---|
| Inshas #1 | 0.496 +/- 0.004 | 0.505 +/- 0.003 | 0.512 +/- 0.003 | 0.521 +/- 0.005 | 0.529 +/- 0.005 | 0.537 +/- 0.004 |
| Inshas #2 | 0.496 +/- 0.008 | 0.506 +/- 0.007 | 0.517 +/- 0.006 | 0.526 +/- 0.009 | 0.533 +/- 0.008 | 0.546 +/- 0.007 |
| Diphenylether (Standard) | 0.382 | 0.388 | 0.395 | 0.398 | 0.405 | 0.412 |
| Diphenylether (Literature value) [a] | 0.382 | 0.388 | 0.394 | 0.401 | 0.407 | 0.414 |

[a] Diphenylether literature values interpolated from D.C. Ginnings and G.T. Furukawa, J. Amer. Chem. Soc. 75, 522 (1953).

TABLE B-8 (Continued)

SPECIFIC HEAT ANALYSES

| Sample | Specific Heat (cal/g/°C) -15 °C | 15 °C | 40 °C |
|---|---|---|---|
| King Fahad (JP-4) | 0.463 +/- 0.002 | 0.496 +/- 0.003 | 0.521 +/- 0.002 |
| King Aziz (JP-4) | 0.445 +/- 0.002 | 0.478 +/- 0.001 | 0.500 +/- 0.002 |
| Beauvechain (JP-4) | 0.442 +/- 0.002 | 0.473 +/- 0.000 | 0.495 +/- 0.004 |
| Kleine Brogen (JP-4) | 0.429 +/- 0.003 | 0.467 +/- 0.003 | 0.485 +/- 0.002 |
| Skrydstru (JP-4) | 0.423 +/- 0.003 | 0.451 +/- 0.001 | 0.479 +/- 0.002 |
| Leeuwarden (JP-8) | 0.416 +/- 0.004 | 0.450 +/- 0.001 | 0.475 +/- 0.000 |
| Volkel (JP-8) | 0.415 +/- 0.003 | 0.446 +/- 0.003 | 0.468 +/- 0.003 |
| Heptane ( >99% purity) | 0.499 +/- 0.000 | 0.530 +/- 0.000 | 0.558 +/- 0.000 |
| Heptane (Literature Value)[a] | 0.505 | 0.528 +/- 0.000 | 0.550 |

[a] API Project 44, Table 23-2-(1.202)-VC

TABLE B-9

COMPARISON OF TYPICAL JP-4 AND JP-8 AND EGYPTIAN F100 SAMPLES
SPECIFIC HEAT AS A FUNCTION OF TEMPERATURE

| Temperature °F (°C) | Specific Heat (cal/g °C) Typical | US F100 Samples | Egyptian Samples |
|---|---|---|---|
| -15 (JP-4) | N/A | - | 0.441 |
| 15 | N/A | - | 0.473 |
| 35 | 0.507 | 0.499 | 0.496 |
| 40 | 0.512 | - | 0.496 |
| 45 | 0.517 | 0.510 | 0.506 |
| 55 | 0.528 | 0.521 | 0.515 |
| 65 | 0.538 | 0.532 | 0.524 |
| 75 | 0.547 | 0.541 | 0.532 |
| 85 | 0.559 | 0.550 | 0.539 |
| -15 (JP-8) | N/A | - | 0.416 |
| 15 | N/A | - | 0.448 |
| 40 | 0.486 | - | 0.472 |

TABLE B-10

TYPICAL JP-8 PROPERTIES AS A FUNCTION OF TEMPERATURE[a]

| Temperature °F (°C) | Vapor pressure (mm Hg) | Kinematic viscosity (centistokes) | Density ($g/cm^3$) | Surface tension (dynes/cm) |
|---|---|---|---|---|
| -30.1 (-34.5) | N/A | 7.50 | 0.847 | 27.51 |
| -20 (-28.9) | N/A | 6.00 | 0.844 | 27.18 |
| - 4 (-20) | N/A | 4.40 | 0.837 | 26.20 |
| 32 (0) | N/A | 2.58 | 0.822 | 24.79 |
| 59 (15) | N/A | 1.81 | 0.812 | 23.70 |
| 70 (21.1) | N/A | 1.63 | 0.807 | 23.20 |
| 100 (37.8) | N/A | 1.22 | 0.796 | 21.90 |
| 140 (60) | 16.12 | 0.90 | 0.779 | 20.20 |

[a]Reference 8.

TABLE B-11

SIMULATED DISTILLATION DATA FOR INSHAS #1 SAMPLE

| % Recovered | Temperature °C | Temperature °F |
|---|---|---|
| 0.5 | 98 | 208 |
| 1.0 | 103 | 217 |
| 5.0 | 137 | 279 |
| 10 | 149 | 300 |
| 20 | 161 | 322 |
| 30 | 170 | 338 |
| 40 | 178 | 352 |
| 50 | 189 | 372 |
| 60 | 198 | 388 |
| 70 | 211 | 412 |
| 80 | 221 | 430 |
| 90 | 235 | 455 |
| 95 | 244 | 471 |
| 99 | 259 | 498 |
| 99.5 | 264 | 507 |

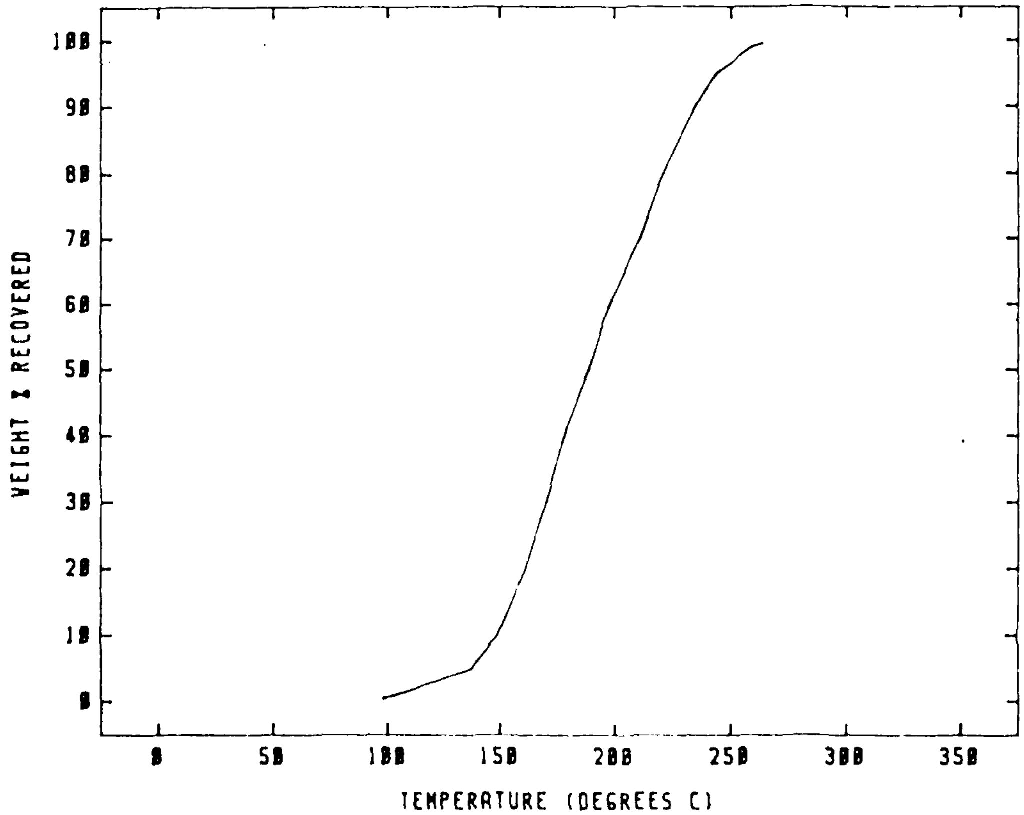


Figure B-15. Distillation Curve for Inshas #1 Sample

TABLE B-12

SIMULATED DISTILLATION DATA FOR INSHAS #2 SAMPLE

| % Recovered | Temperature °C | °F |
|---|---|---|
| 0.5 | 98 | 208 |
| 1.0 | 104 | 219 |
| 5.0 | 137 | 279 |
| 10 | 149 | 300 |
| 20 | 160 | 320 |
| 30 | 169 | 336 |
| 40 | 177 | 351 |
| 50 | 188 | 370 |
| 60 | 198 | 388 |
| 70 | 210 | 410 |
| 80 | 220 | 428 |
| 90 | 235 | 455 |
| 95 | 244 | 471 |
| 99 | 260 | 500 |
| 99.5 | 268 | 514 |

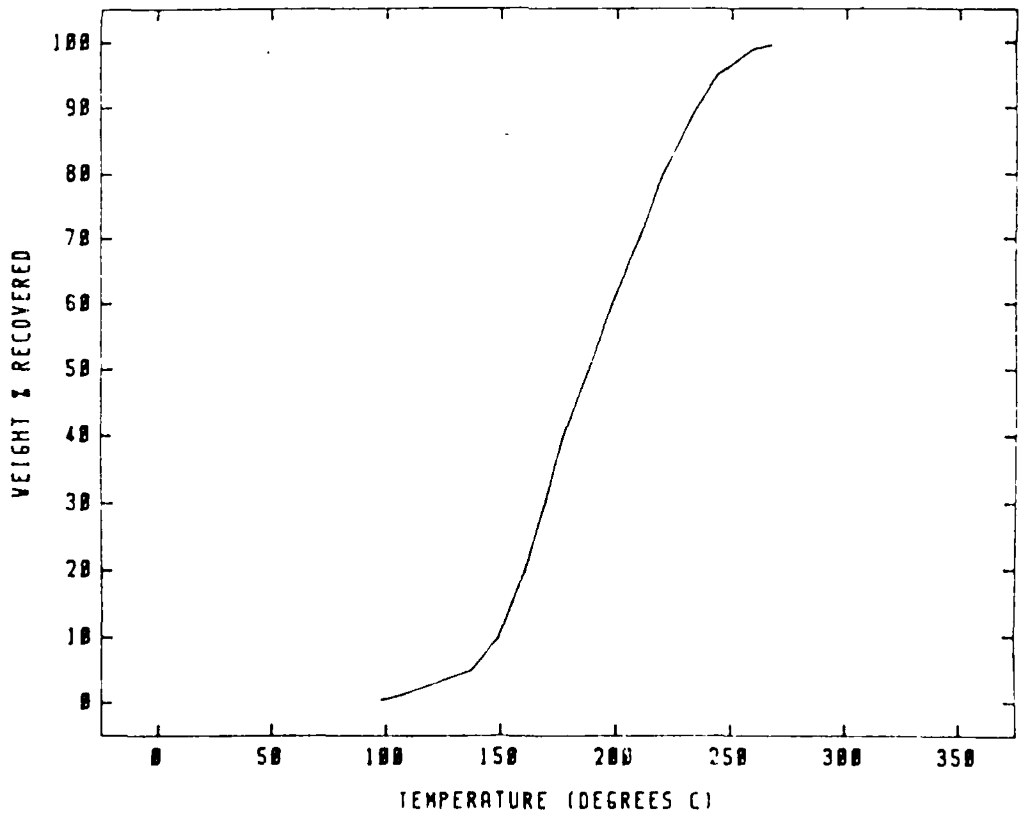


Figure B-16. Distillation Curve for Inshas #2 Sample

AD-A160 573 F100 FUEL SAMPLING ANALYSIS: FOREIGN SAMPLES(U) AIR FORCE WRIGHT AERONAUTICAL LABS WRIGHT-PATTERSON AFB OH L O MAURICE MAR 86 AFWAL-TR-85-2087 2/2

UNCLASSIFIED F/G 21/4 NL

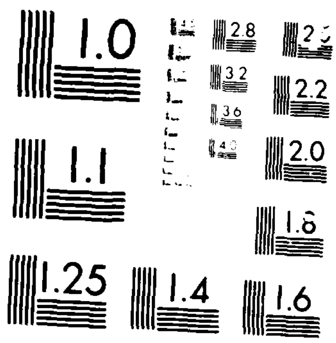
1.0
2.8
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

TABLE 13

SIMULATED DISTILLATION DATA FOR EGYPT JP-4 SAMPLE

| % Recovered | Temperature °C | Temperature °F |
|---|---|---|
| 0.5 | 98 | 209 |
| 1.0 | 108 | 227 |
| 5.0 | 136 | 277 |
| 10 | 146 | 296 |
| 20 | 159 | 318 |
| 30 | 168 | 335 |
| 40 | 176 | 349 |
| 50 | 189 | 371 |
| 60 | 199 | 389 |
| 70 | 214 | 418 |
| 80 | 228 | 442 |
| 90 | 243 | 470 |
| 95 | 262 | 503 |
| 99 | 332 | 629 |
| 99.5 | 345 | 654 |

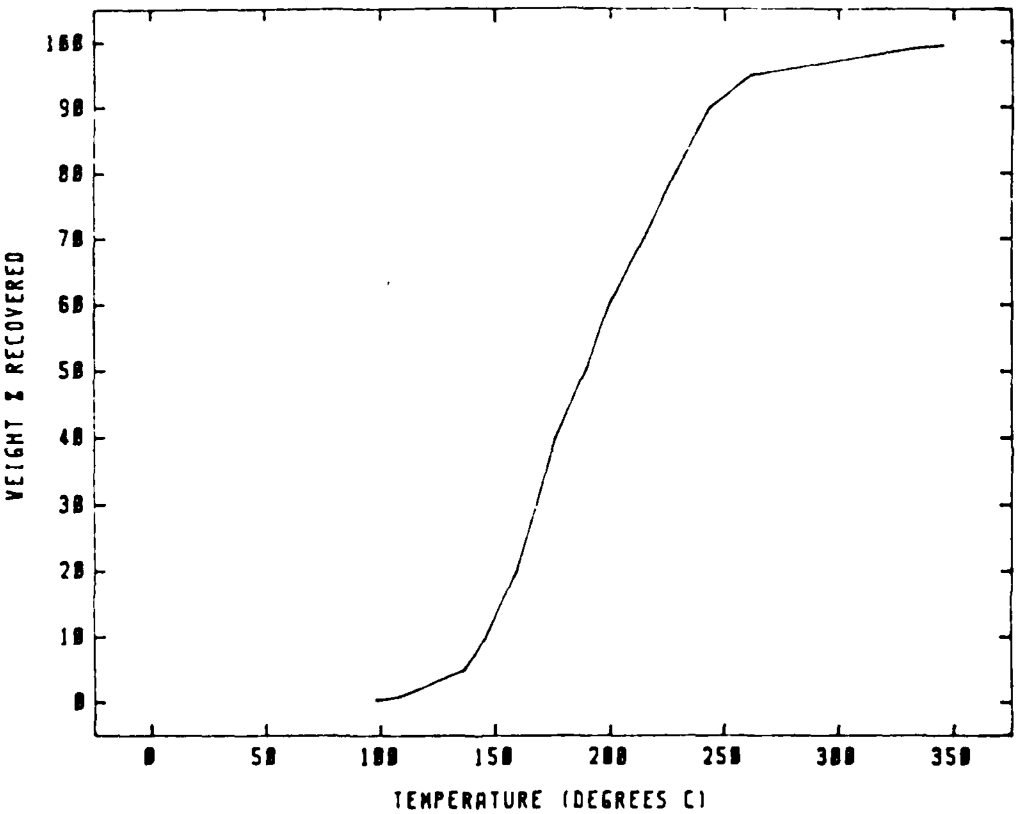


Figure B-17. Distillation Curve for Egypt JP-4 Sample

TABLE B-14

SIMULATED DISTILLATION DATA FOR KING FAHAD SAMPLE

| % Recovered | Temperature °C | Temperature °F |
|---|---|---|
| 0.5 | 31 | 88 |
| 1.0 | 32 | 90 |
| 5.0 | 58 | 136 |
| 10 | 70 | 158 |
| 20 | 100 | 212 |
| 30 | 133 | 271 |
| 40 | 161 | 322 |
| 50 | 177 | 351 |
| 60 | 192 | 378 |
| 70 | 203 | 397 |
| 80 | 219 | 426 |
| 90 | 236 | 457 |
| 93 | 248 | 478 |
| 99 | 269 | 516 |
| 99.5 | 275 | 527 |

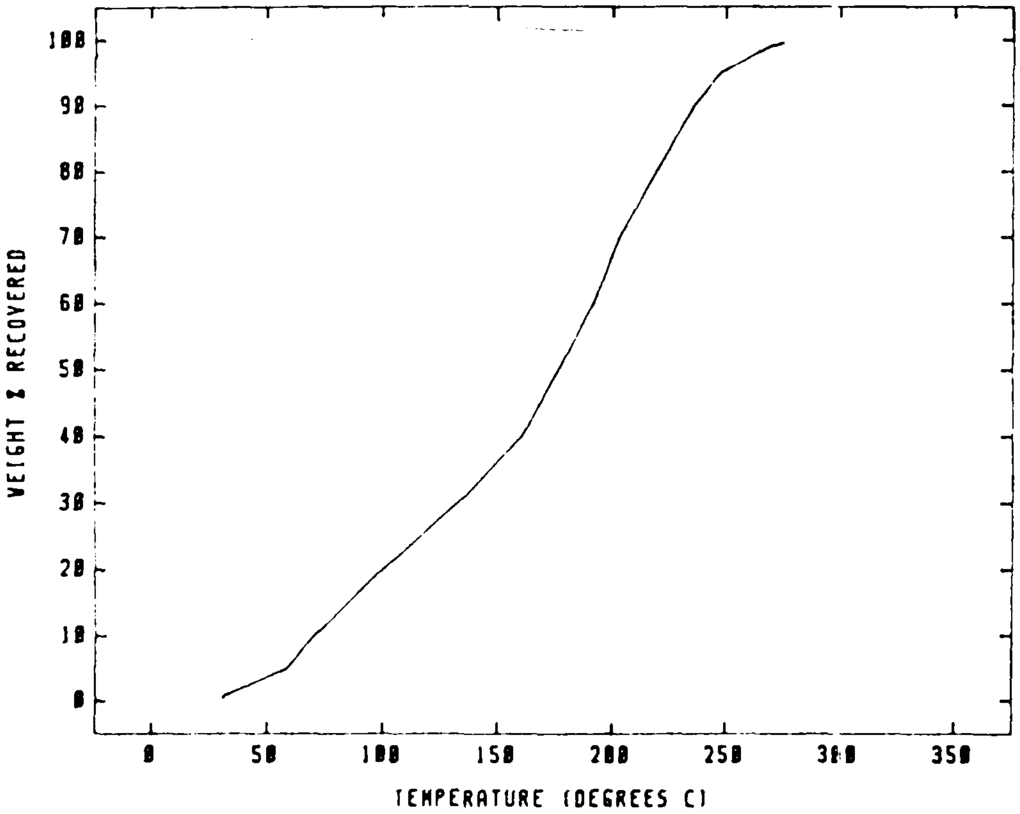


Figure B-18. Distillation Curve for King Fahad Sample

TABLE B-15

SIMULATED DISTILLATION DATA FOR KING AZIZ SAMPLE

| % Recovered | Temperature °C | °F |
|---|---|---|
| 0.5 | 27 | 81 |
| 1.0 | 29 | 84 |
| 5.0 | 54 | 129 |
| 10 | 65 | 149 |
| 20 | 95 | 203 |
| 30 | 127 | 261 |
| 40 | 153 | 307 |
| 50 | 171 | 340 |
| 60 | 185 | 365 |
| 70 | 196 | 385 |
| 80 | 213 | 415 |
| 90 | 231 | 448 |
| 95 | 244 | 471 |
| 99 | 270 | 518 |
| 99.5 | 284 | 543 |

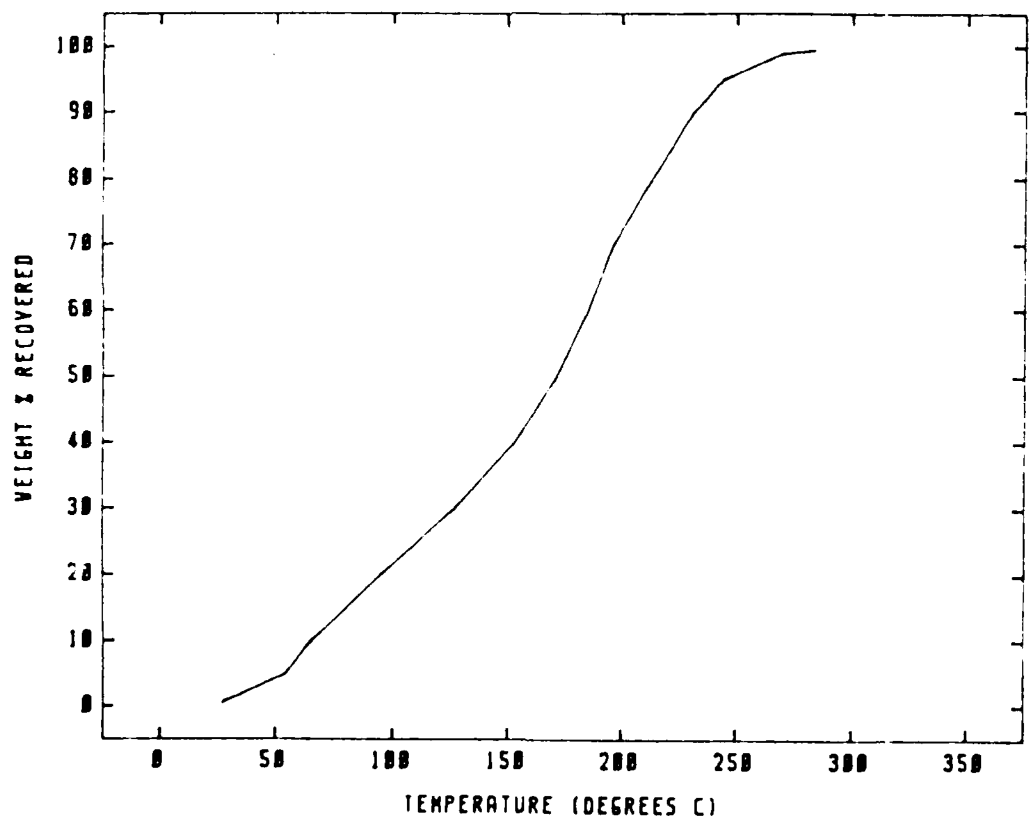


Figure B-19. Distillation Curve for King Aziz Sample

TABLE B-16

SIMULATED DISTILLATION DATA FOR JAPAN SAMPLE

| % Recovered | Temperature $^{o}C$ | Temperature $^{o}F$ |
|---|---|---|
| 0.5 | 27 | 80 |
| 1.0 | 28 | 83 |
| 5.0 | 58 | 136 |
| 10 | 72 | 161 |
| 20 | 99 | 210 |
| 30 | 119 | 246 |
| 40 | 139 | 282 |
| 50 | 157 | 315 |
| 60 | 175 | 347 |
| 70 | 192 | 378 |
| 80 | 210 | 410 |
| 90 | 230 | 446 |
| 95 | 242 | 468 |
| 99 | 266 | 510 |
| 99.5 | 275 | 526 |

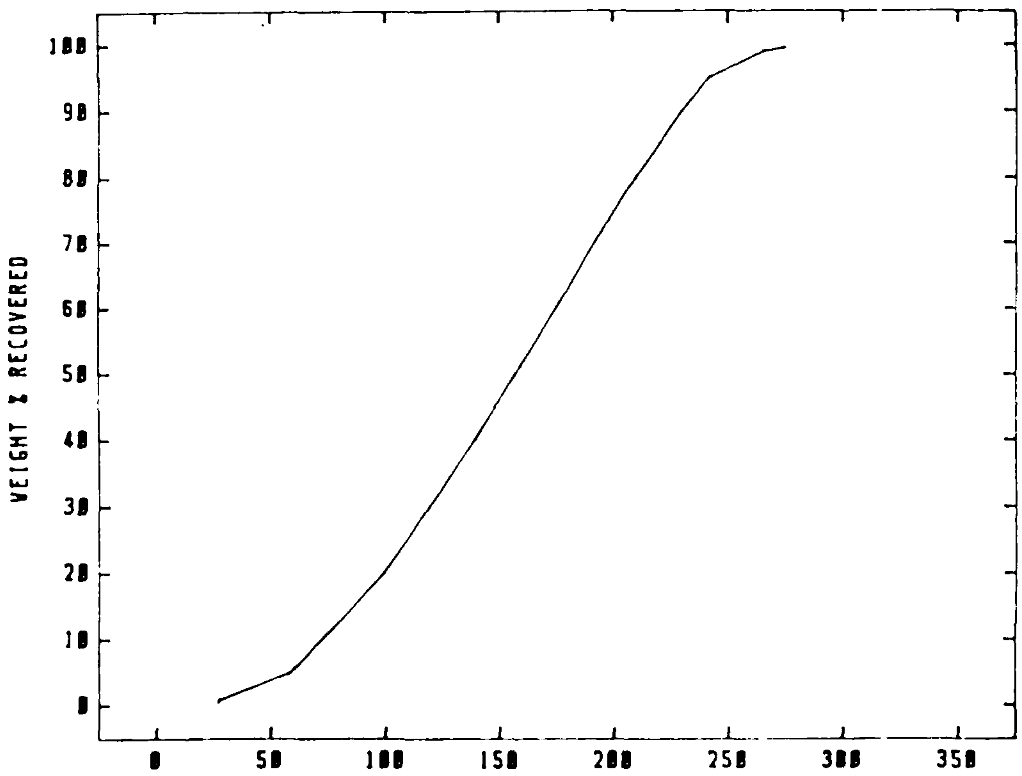


Figure B-20. Distillation Curve for Japan Sample

TABLE B-17

SIMULATED DISTILLATION DATA FOR PAKISTAN SAMPLE

| % Recovered | Temperature °C | Temperature °F |
|---|---|---|
| 0.5 | 28 | 82 |
| 1.0 | 30 | 85 |
| 5.0 | 58 | 136 |
| 10 | 74 | 165 |
| 20 | 102 | 215 |
| 30 | 122 | 251 |
| 40 | 136 | 277 |
| 50 | 150 | 302 |
| 60 | 166 | 330 |
| 70 | 184 | 362 |
| 80 | 205 | 401 |
| 90 | 230 | 446 |
| 95 | 245 | 473 |
| 99 | 267 | 513 |
| 99.5 | 278 | 532 |

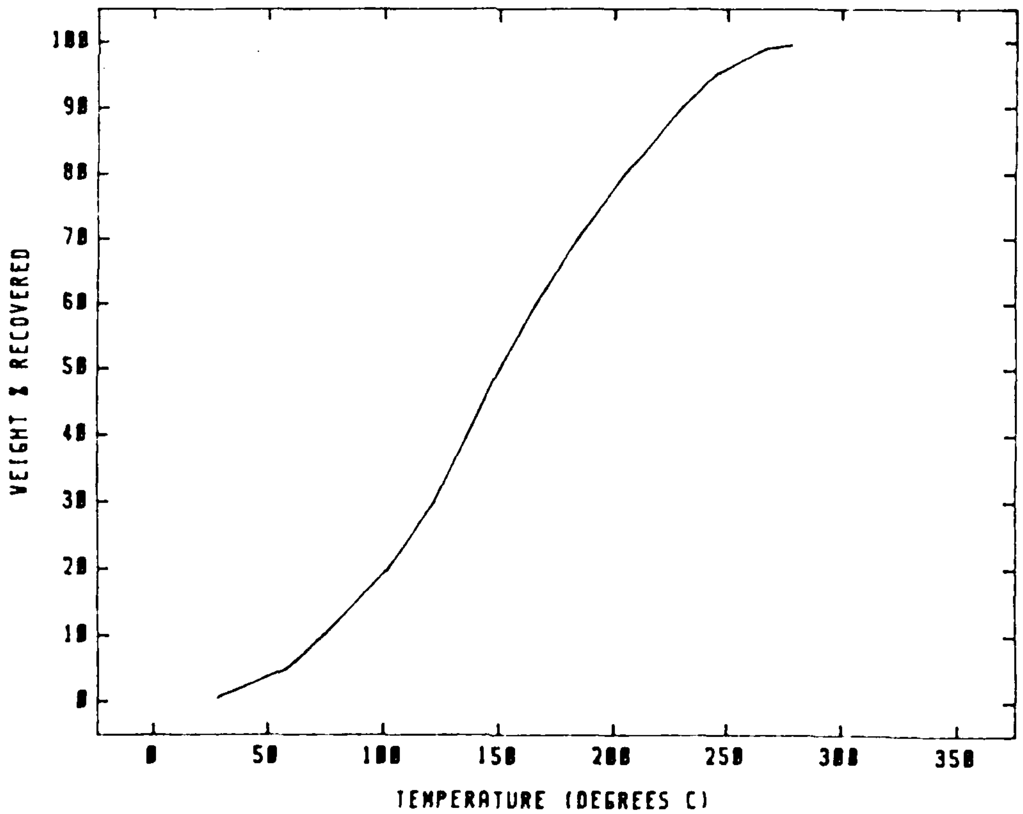


Figure B-21. Distillation Curve for Pakistan Sample

TABLE B-18

SIMULATED DISTILLATION DATA FOR BEAUVECHAIN SAMPLE

| % Recovered | Temperature °C | °F |
|---|---|---|
| 0.5 | 29 | 84 |
| 1.0 | 30 | 86 |
| 5.0 | 36 | 96 |
| 10 | 57 | 135 |
| 20 | 90 | 193 |
| 30 | 110 | 230 |
| 40 | 130 | 266 |
| 50 | 151 | 304 |
| 60 | 171 | 339 |
| 70 | 187 | 369 |
| 80 | 204 | 399 |
| 90 | 223 | 434 |
| 95 | 235 | 456 |
| 99 | 256 | 493 |
| 99.5 | 263 | 505 |

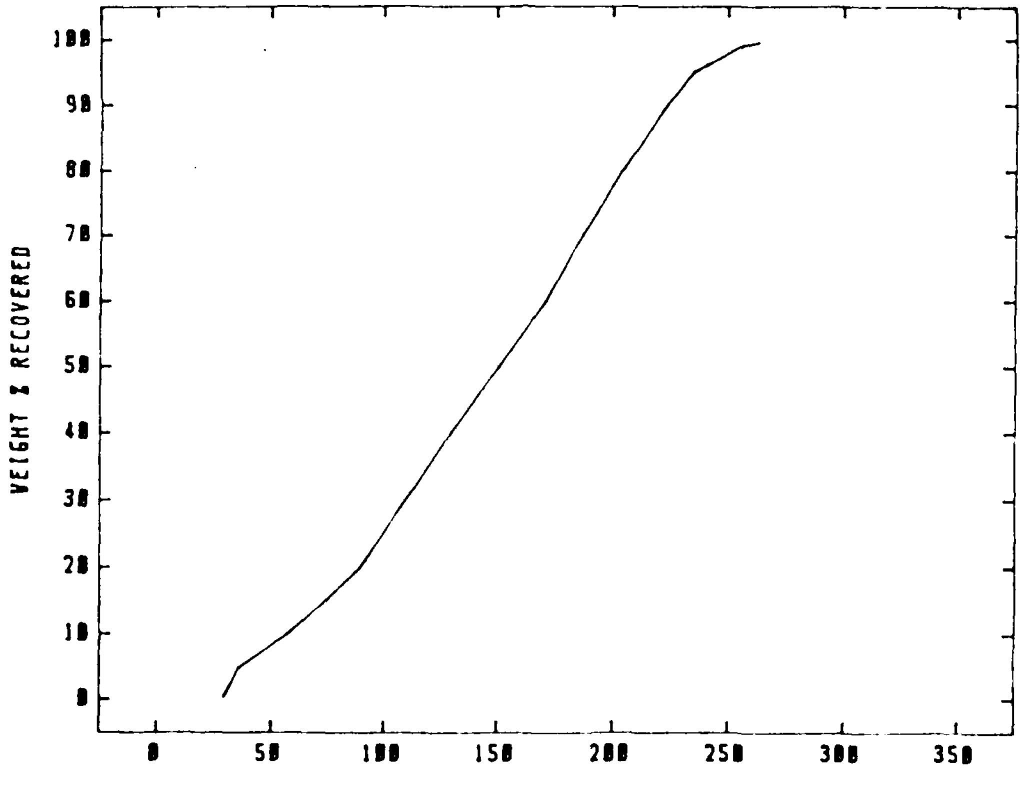


Figure B-22. Distillation Curve for Beauvechain Sample

TABLE B-19

SIMULATED DISTILLATION DATA FOR KLEINE BROGEN SAMPLE

| % Recovered | Temperature °C | Temperature °F |
|---|---|---|
| 0.5 | 29 | 84 |
| 1.0 | 34 | 93 |
| 5.0 | 54 | 129 |
| 10 | 66 | 150 |
| 20 | 88 | 191 |
| 30 | 109 | 229 |
| 40 | 135 | 276 |
| 50 | 158 | 317 |
| 60 | 174 | 346 |
| 70 | 192 | 378 |
| 80 | 209 | 409 |
| 90 | 231 | 447 |
| 95 | 244 | 471 |
| 99 | 264 | 507 |
| 99.5 | 271 | 520 |

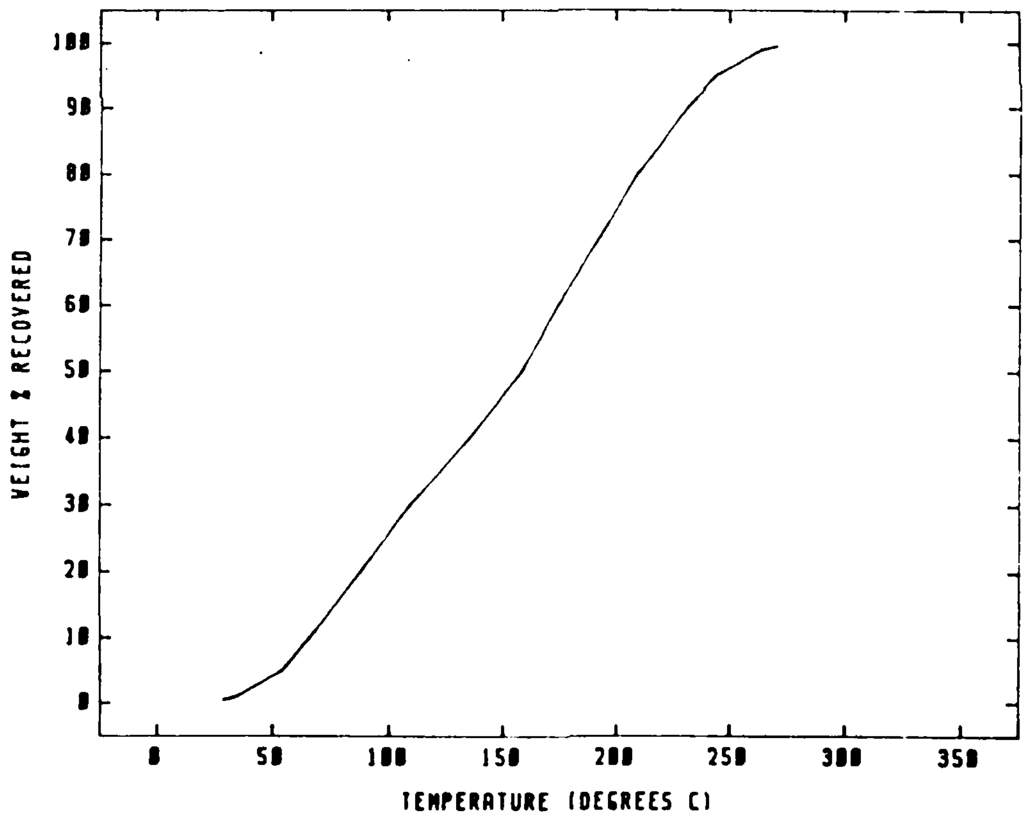


Figure B-23. Distillation Curve for Kleine Brogen Sample

TABLE B-20

SIMULATED DISTILLATION DATA FOR SKRYDSTRU SAMPLE

| % Recovered | Temperature °C | Temperature °F |
|---|---|---|
| 0.5 | 14 | 58 |
| 1.0 | 16 | 61 |
| 5.0 | 79 | 174 |
| 10 | 91 | 195 |
| 20 | 112 | 234 |
| 30 | 128 | 263 |
| 40 | 145 | 292 |
| 50 | 162 | 324 |
| 60 | 177 | 350 |
| 70 | 195 | 383 |
| 80 | 213 | 415 |
| 90 | 232 | 449 |
| 95 | 244 | 471 |
| 99 | 263 | 505 |
| 99.5 | 268 | 515 |

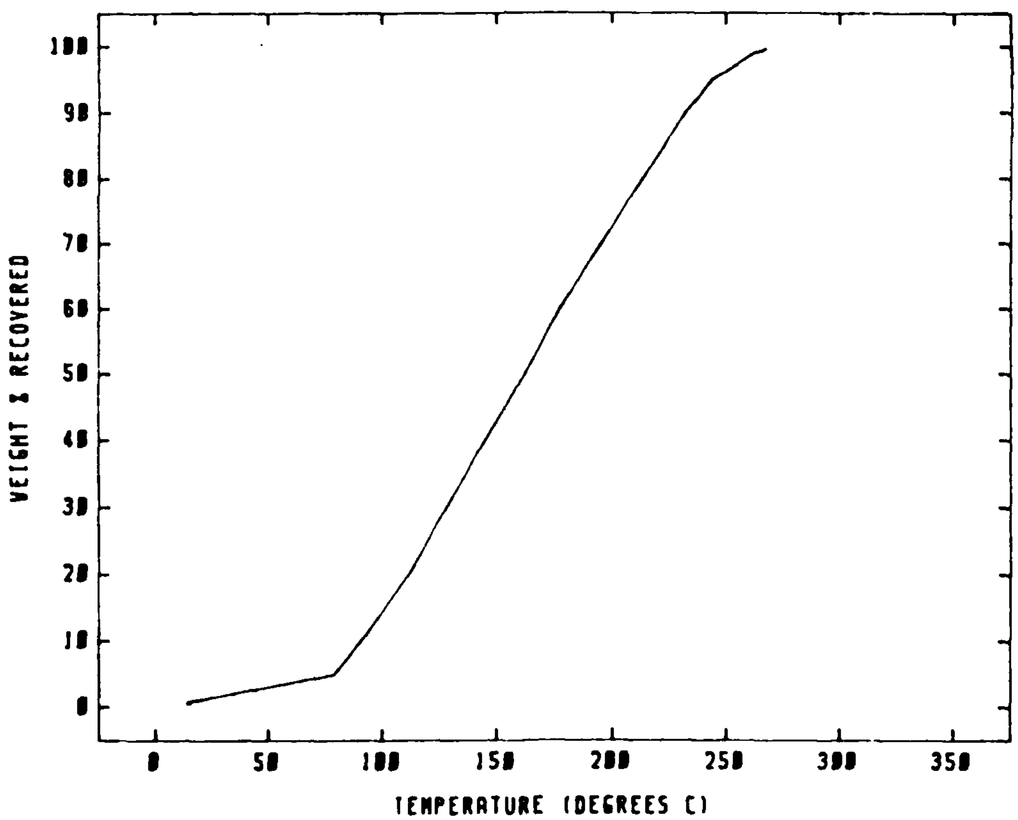


Figure B-24. Distillation Curve for Skrydstru Sample

TABLE B-21

SIMULATED DISTILLATION DATA FOR RYGGE SAMPLE

| % Recovered | Temperature °C | °F |
|---|---|---|
| 0.5 | 37 | 99 |
| 1.0 | 52 | 126 |
| 5.0 | 63 | 145 |
| 10 | 87 | 189 |
| 20 | 119 | 246 |
| 30 | 158 | 316 |
| 40 | 175 | 347 |
| 50 | 187 | 369 |
| 60 | 196 | 385 |
| 70 | 203 | 397 |
| 80 | 214 | 417 |
| 90 | 225 | 437 |
| 95 | 235 | 455 |
| 99 | 255 | 419 |
| 99.5 | 264 | 507 |

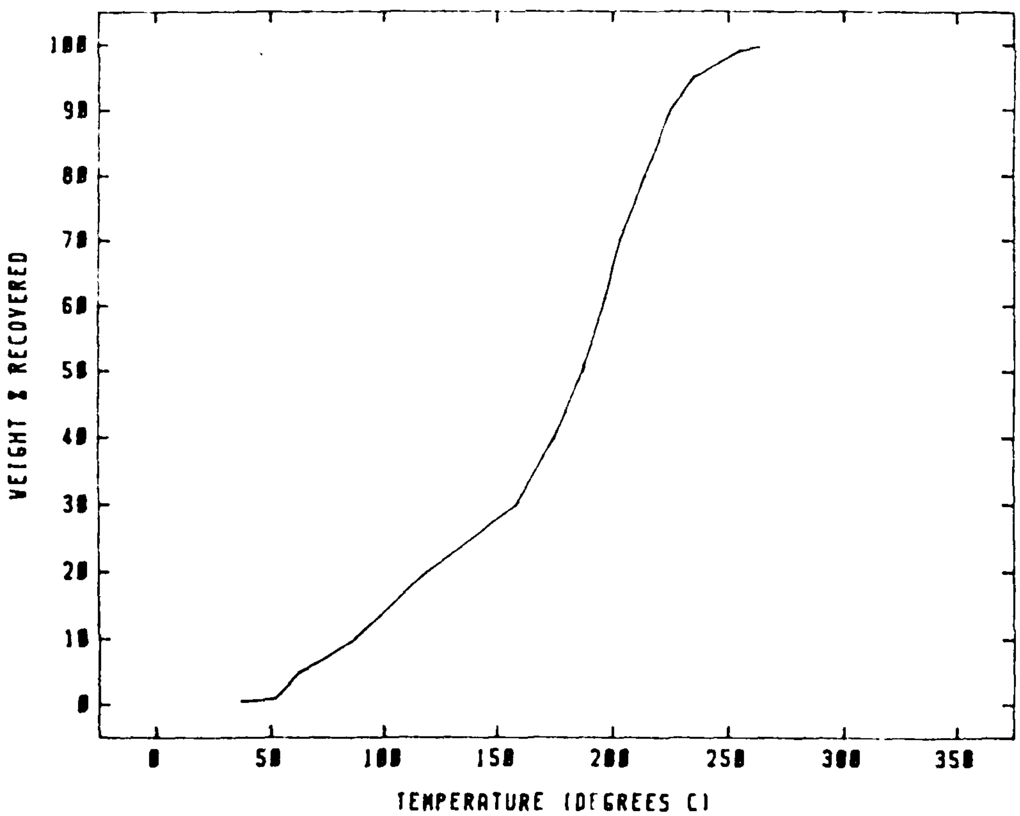


Figure B-25. Distillation Curve for Rygge Sample

TABLE B-22

SIMULATED DISTILLATION DATA FOR EGYPT JP-8 SAMPLE

| % Recovered | Temperature °C | °F |
|---|---|---|
| 0.5 | 98 | 209 |
| 1.0 | 102 | 216 |
| 5.0 | 136 | 278 |
| 10 | 150 | 302 |
| 20 | 164 | 328 |
| 30 | 175 | 347 |
| 40 | 183 | 361 |
| 50 | 196 | 384 |
| 60 | 203 | 398 |
| 70 | 216 | 422 |
| 80 | 227 | 441 |
| 90 | 239 | 462 |
| 95 | 252 | 485 |
| 99 | 270 | 519 |
| 99.5 | 279 | 535 |

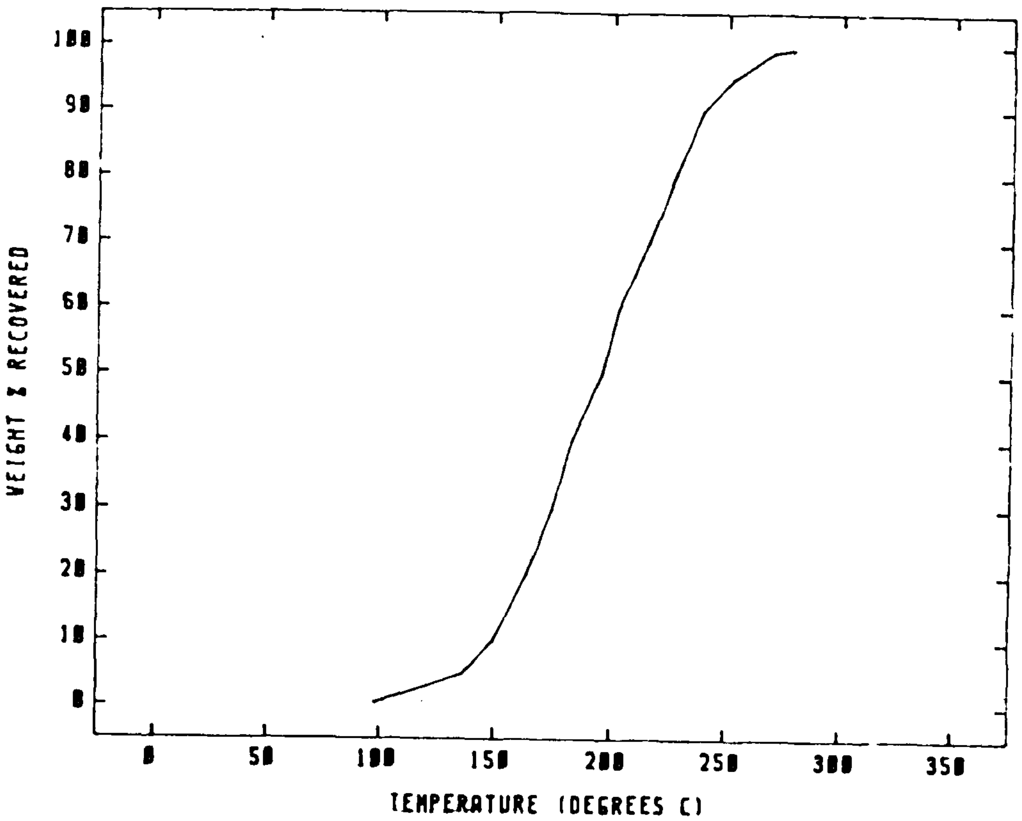


Figure B-26. Distillation Curve for Egypt JP-8 Sample

TABLE B-23

SIMULATED DISTILLATION DATA FOR VENEZUELA SAMPLE

| % Recovered | Temperature °C | °F |
|---|---|---|
| 0.5 | 130 | 265 |
| 1.0 | 140 | 283 |
| 5.0 | 157 | 315 |
| 10 | 164 | 325 |
| 20 | 175 | 346 |
| 30 | 185 | 364 |
| 40 | 196 | 384 |
| 50 | 207 | 405 |
| 60 | 219 | 426 |
| 70 | 232 | 449 |
| 80 | 247 | 476 |
| 90 | 263 | 506 |
| 95 | 276 | 529 |
| 99 | 303 | 578 |
| 99.5 | 310 | 590 |

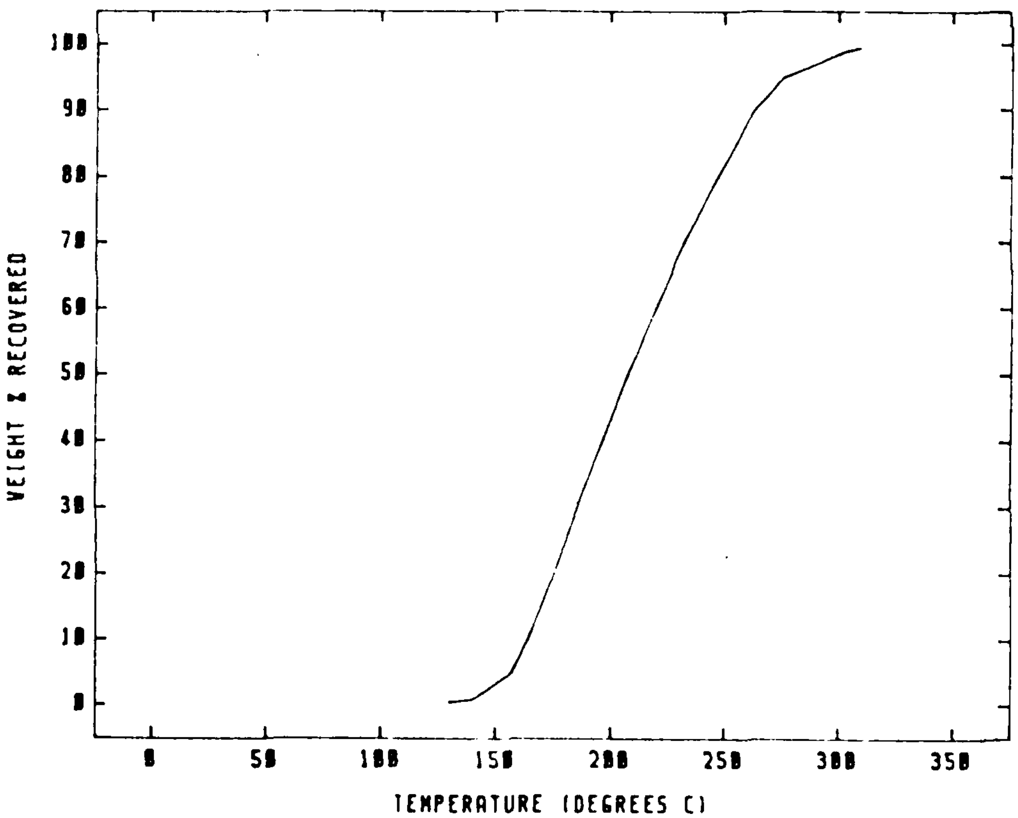


Figure B-27. Distillation Curve for Venezuela Sample

TABLE B-24

SIMULATED DISTILLATION DATA FOR LEEUWARDEN SAMPLE

| % Recovered | Temperature °C | °F |
|---|---|---|
| 0.5 | 118 | 244 |
| 1.0 | 126 | 259 |
| 5.0 | 150 | 302 |
| 10 | 162 | 324 |
| 20 | 175 | 346 |
| 30 | 187 | 368 |
| 40 | 195 | 383 |
| 50 | 204 | 400 |
| 60 | 215 | 419 |
| 70 | 223 | 434 |
| 80 | 235 | 455 |
| 90 | 251 | 484 |
| 95 | 264 | 507 |
| 99 | 284 | 543 |
| 99.5 | 288 | 550 |

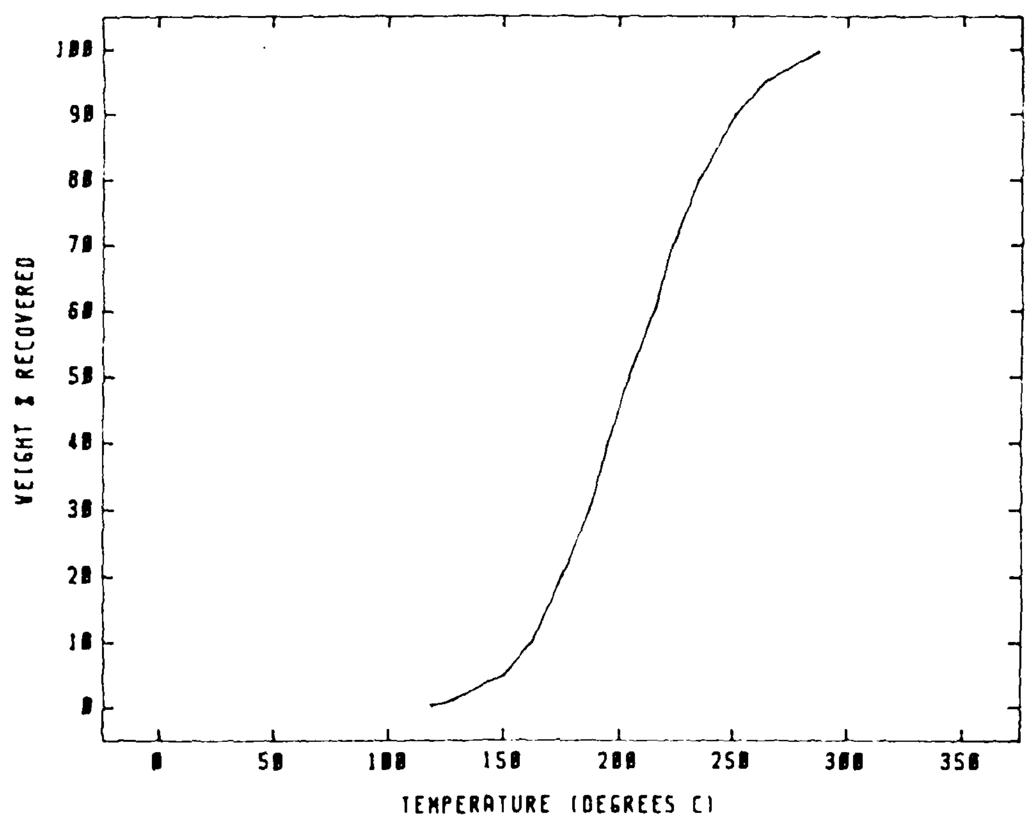


Figure B-28. Distillation Curve for Leeuwarden Sample

TABLE B-25

SIMULATED DISTILLATION DATA FOR VOLKEL SAMPLE

| % Recovered | Temperature °C | Temperature °F |
|---|---|---|
| 0.5 | 92 | 197 |
| 1.0 | 99 | 211 |
| 5.0 | 131 | 267 |
| 10 | 149 | 300 |
| 20 | 166 | 330 |
| 30 | 175 | 346 |
| 40 | 184 | 364 |
| 50 | 194 | 382 |
| 60 | 202 | 396 |
| 70 | 214 | 417 |
| 80 | 226 | 438 |
| 90 | 241 | 465 |
| 95 | 253 | 488 |
| 99 | 269 | 516 |
| 99.5 | 272 | 521 |

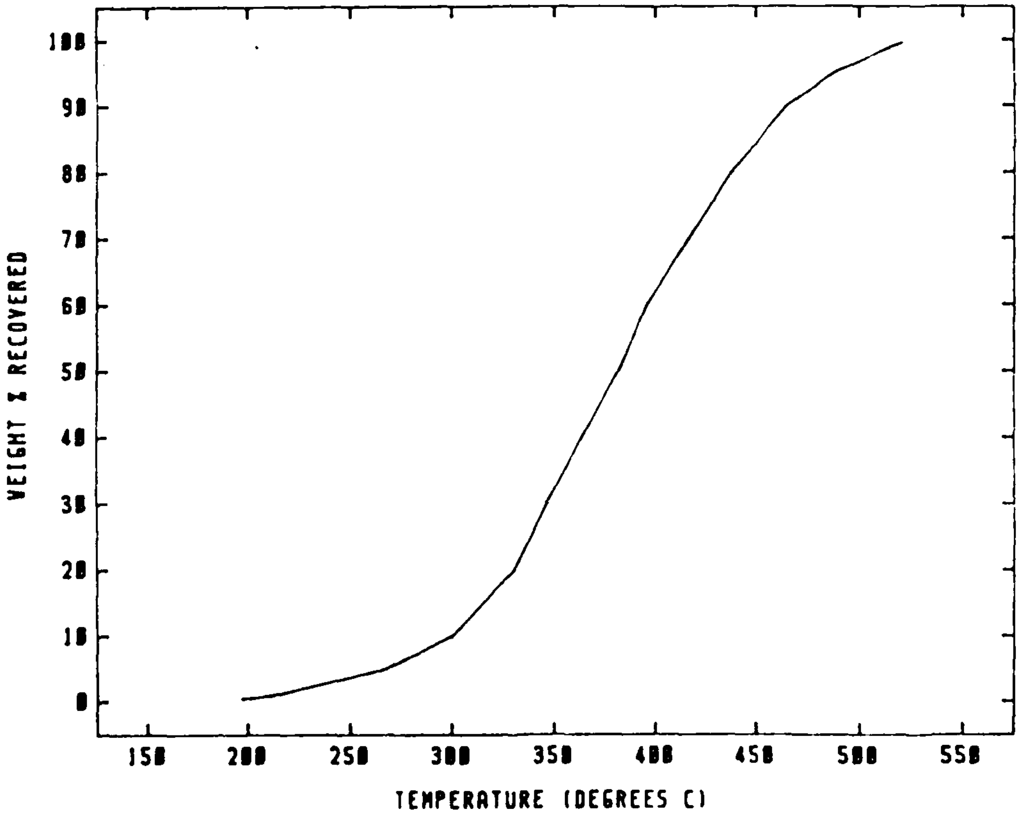


Figure B-29. Simulated Distillation Curve for Volkel Sample

TABLE B-26

HYDROCARBON TYPE ANALYSES

| | INSHAS #1 | | INSHAS #2 | | EGYPT JP-4 | | KING FAHAD | | KING AZIZ | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ASTM[a] | Monsanto[b] | ASTM | Monsanto | ASTM | Monsanto | ASTM | Monsanto | ASTM | Monsanto |
| Paraffins | 49.2 | 47.0 | 49.3 | 47.0 | 50.1 | 47.8 | 64.6 | 59.5 | 64.8 | 59.4 |
| Cycloparaffins | 33.2 | -[c] | 33.1 | - | 34.7 | - | 17.3 | - | 16.9 | - |
| Dicycloparaffins | 0 | - | 0 | - | 0 | - | 2.5 | - | 2.6 | - |
| Total cycloparaffins | 33.2[d] | 32.1 | 33.1 | 32.2 | 34.7 | 33.1 | 19.8 | 19.4 | 19.5 | 19.5 |
| Alkylbenzenes | 13.3 | 16.7 | 13.5 | 16.8 | 12.3 | 16.2 | 13.1 | 19.6 | 13.3 | 19.7 |
| Indans and tetralins | 2.1 | 2.0 | 2.0 | 1.9 | 1.5 | 1.6 | 1.7 | 1.5 | 1.6 | 1.4 |
| Indenes and dihydronaphthalenes | - | 0 | - | 0 | - | 0 | - | 0 | - | 0 |
| Naphthalenes | 2.2 | 2.2 | 2.1 | 2.1 | 1.4 | 1.3 | 0.8 | 0 | 0.8 | 0 |
| Average carbon no. | N/A | | N/A | | 10.1 | | 8.7 | | 8.6 | |

[a]Modification of ASTM Method D 2789, values converted from volume percent using relative densities.

[b]Monsanto Method 21-PQ-38-63.

[c]Dash indicates method does not provide information on this compound category.

[d]Sum of two preceding values.

TABLE B-26 (Continued)

| | JAPAN | | PAKISTAN | | BEAUVECHAIN | | KLEINE BROGEN | | SKRYDSTRU | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ASTM[a] | Monsanto[b] | ASTM | Monsanto | ASTM | Monsanto | ASTM | Monsanto | ASTM | Monsanto |
| Paraffins | 62.4 | 56.7 | 63.4 | 57.8 | 53.3 | 45.9 | 58.5 | 52.5 | 56.1 | 51.0 |
| Cycloparaffins | 20.9 | -[c] | 19.0 | - | 27.9 | - | 24.8 | - | 27.5 | - |
| Dicycloparaffins | 2.5 | - | 2.1 | - | 4.9 | - | 4.0 | - | 5.3 | - |
| Total cyclo-paraffins | 23.4[d] | 23.3 | 21.1 | 21.0 | 38.8 | 35.3 | 28.8 | 30.0 | 32.8 | 33.6 |
| Alkylbenzenes | 12.1 | 18.4 | 13.4 | 20.5 | 11.1 | 16.7 | 10.3 | 15.8 | 9.5 | 13.7 |
| Indans and tetralins | 1.6 | 1.6 | 1.1 | 0.7 | 1.8 | 1.8 | 1.5 | 1.5 | 1.5 | 1.7 |
| Indenes and di-hydronaphthalenes | - | 0 | - | 0 | - | 0 | - | 0 | - | 0 |
| Naphthalenes | 0.5 | 0 | 1.0 | 0 | 1.0 | 0.3 | 0.9 | 0.2 | 0.1 | 0 |
| Average carbon no. | 8.7 | | 8.5 | | 8.6 | | 8.7 | | 9.0 | |

[a] Modification of ASTM Method D 2789, values converted from volume percent using relative densities.
[b] Monsanto Method 21-PQ-38-63.
[c] Dash indicates method does not provide information on this specific compound category.
[d] Sum of two preceding values.

TABLE B-26 (Continued)

| | BODO | | RYGGE | | EGYPT JP-8 | | VENEZUELA | | LEEUWARDEN | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ASTM[a] | Monsanto[b] | ASTM | Monsanto | ASTM | Monsanto | ASTM | Monsanto | ASTM | Monsanto |
| Paraffins | 51.5 | 43.9 | 50.5 | 47.9 | 47.0 | 44.5 | 38.3 | 37.6 | 48.8 | 48.1 |
| Cycloparaffins | 29.2 | -[c] | 33.2 | - | 32.3 | - | 41.1 | - | 34.8 | - |
| Dicycloparaffins | 2.2 | - | 0 | - | 0.3 | - | 0.5 | - | 0 | - |
| Total cyclo- paraffins | 31.4[d] | 32.9 | 33.2 | 31.5 | 32.6 | 31.6 | 41.6 | 40.6 | 34.8 | 33.9 |
| Alkylbenzenes | 16.0 | 23.2 | 13.0 | 17.5 | 13.6 | 16.5 | 12.7 | 15.0 | 10.6 | 13.2 |
| Indans and tetralins | 0.4 | 0 | 3.0 | 2.8 | 2.5 | 2.3 | 4.4 | 3.8 | 4.7 | 3.9 |
| Indenes and di- hydronaphthalenes | - | 0 | - | 0 | - | 0 | - | 0 | - | 0 |
| Naphthalenes | 0.7 | 0 | 0.3 | 0.3 | 4.3 | 5.1 | 3.0 | 3.0 | 1.1 | 0.9 |
| Average carbon no. | 8.0 | | 9.1 | | N/A | | 10.6 | | 10.5 | |

Modification of ASTM Method D 2789, values converted from volume percent using relative densities.
Monsanto Method 21-PQ-38-63.
Dash indicates method does not provide information on this specific compound category.
Sum of two preceding values.

TABLE B-26 (Concluded)

| | VOLKEL | |
|---|---|---|
| | ASTM[a] | Monsanto[b] |
| Paraffins | 43.7 | 41.9 |
| Cycloparaffins | 36.9 | -[c] |
| Dicycloparaffins | 0 | - |
| Total cyclo-paraffins | 36.9[d] | 36.1 |
| Alkylbenzenes | 13.6 | 16.8 |
| Indans and tetralins | 3.1 | 2.7 |
| Indenes and di-hydronaphthalenes | - | 0 |
| Naphthalenes | 2.7 | 2.5 |
| Average carbon no. | 10.1 | - |

[a] Modification of ASTM Method D 2789, values converted from volume percent using relative densities.
[b] Monsanto Method 21-PQ-38-63.
[c] Dash indicates method does not provide information on this specific compound category.
[d] Sum of two preceding values.

TABLE B-27

AVERAGE HYDROCARBON TYPES

| | US F100 JP-4 | FOREIGN JP-4 | FOREIGN JP-8 |
|---|---|---|---|
| Paraffins | 53.50 | 56.1 | 44.5 |
| Cycloparaffins | 27.40 | 26.5 | 36.3 |
| Dicycloparaffins | 4.01 | 2.2 | 0.2 |
| Paraffin/cycloparaffins | 84.90 | 84.8 | 81.0 |
| Alkylbenzene | 12.80 | 12.6 | 12.6 |
| Indans and tetralins | 1.50 | 1.7 | 4.0 |
| Naphthalenes | 0.80 | 1.0 | 2.8 |
| Total aromatics | 15.00 | 15.3 | 19.4 |

## REFERENCES

1. R.H. Perry, C.H. Chilton, Chemical Engineer's Handbook McGraw Hill, Inc., New York, 1973.

2. 1981 Annual Book of ASTM Standards, American Society for Testing and Materials, Philadelphia, 1981.

3. W.E. Harrison, The Chemical and Physical Properties of JP-4 for 1980-1981, Air Force Aero Propulsion Laboratory, Wright-Patterson AFB, Ohio 45433, AFWAL-TR-85-2052, June 1982.

4. L.O. Maurice, F100 Fuel Sampling Analysis, Aero Propulsion Laboratory, Wright-Patterson AFB, Ohio 4533-6563, AFWAL-TR-85-2045, March 1985.

5. J. Petraca, Aviation Turbine Fuel Lubricity Evaluation of Corrosion Inhibitors, Air Force Aero Propulsion Laboratory, Wright-Patterson AFB, Ohio 45433, AFWAL-TR-75-47.

6. R.N. Hodgson, E.A. Steinmetz, et al, Analysis of Aircraft Fuels and Related Materials, Air Force Aero Propulsion Laboratory, Wright-Patterson AFB, Ohio 45433, AFWAL-TR-82-2082.

7. Maxwell Smith, Aviation Fuels, GT Foulis and 10 Ltd, Oxforshire UK 1970.

8. Aviation Fuel Properties, Coordinating Research Council, Atlanta, Georgia, CRC Report No. 530, 1983.

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